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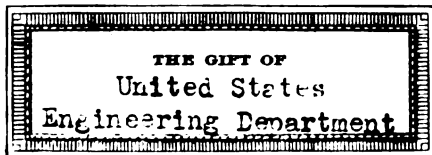
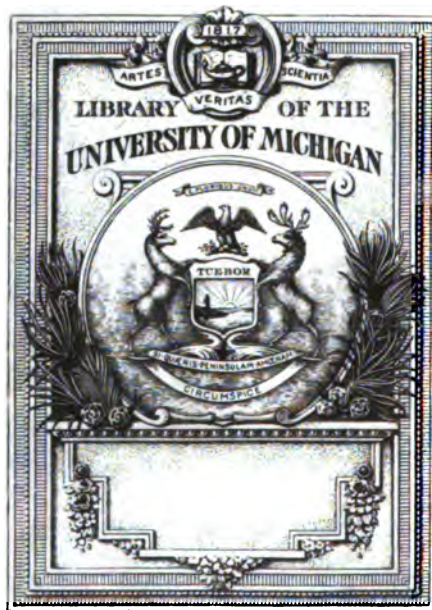
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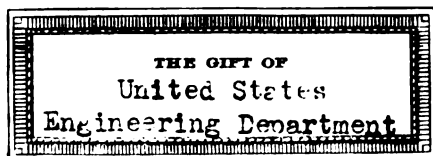
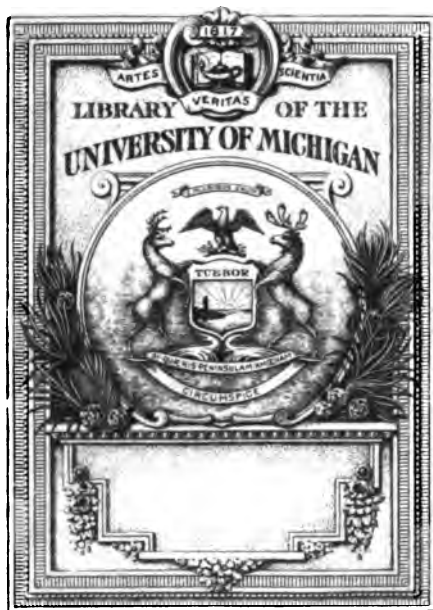
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Diversion of Water from the Grèat Lakes and Niagara River

LETTER FROM THE SECRETARY OF WAR

TRANSMITTING

**WITH A LETTER FROM THE CHIEF OF ENGINEERS, REPORTS
BY COL. J. G. WARREN, CORPS OF ENGINEERS, AND THE
BOARD OF ENGINEERS FOR RIVERS AND HARBORS, OF AN
INVESTIGATION AUTHORIZED BY PUBLIC RESOLUTION NO. 8,
SIXTY-FIFTH CONGRESS, OF THE SUBJECT OF WATER
DIVERSION FROM THE GREAT LAKES AND THE NIAGARA
RIVER, INCLUDING NAVIGATION, SANITARY, AND POWER
PURPOSES, AND THE PRESERVATION OF THE SCENIC BEAUTY
OF NIAGARA FALLS AND THE RAPIDS OF NIAGARA RIVER.**

(Including plates 1-57.)



**WASHINGTON
GOVERNMENT PRINTING OFFICE
1921**

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Engineering and Survey
1911

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LETTER OF SUBMITTAL.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, November 9, 1920.

From: The Chief of Engineers, United States Army.

To: The Secretary of War.

Subject: Diversion of water from the Great Lakes.

1. There is submitted herewith for transmission to Congress, report dated August 30, 1919, with maps and appendices, by Col. J. G. Warren, Corps of Engineers, division engineer, Lakes Division, on investigation of water diversion from Great Lakes and Niagara River, including navigation, sanitary and power purposes, and the preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River, authorized by public resolution No. 8, Sixty-fifth Congress, approved June 30, 1917, in the following language:

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That public resolution numbered forty-five of the Sixty-fourth Congress, approved January 19, 1917, entitled "Joint resolution authorizing the Secretary of War to issue permits for additional diversion of water from the Niagara River," is continued in full force and effect, and under the same conditions, restrictions, and limitations, until July 1, 1918: Provided, That the Secretary of War is hereby authorized and directed to make a comprehensive and thorough investigation, including all necessary surveys and maps, of the entire subject of water diversion from the Great Lakes and the Niagara River, including navigation, sanitary and power purposes, and the preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River, and to report to Congress thereon at the earliest practicable date. To carry out the provisions of this proviso there is hereby appropriated, out of any money in the Treasury not otherwise appropriated, the sum of \$25,000.

The investigation has involved a great amount of work, and the report thereon is a valuable and exhaustive treatment of the subject.

2. This report has been referred, as required by law, to the Board of Engineers for Rivers and Harbors, and attention is invited to its report herewith, dated August 24, 1920. The board has reviewed in detail and commented upon the several problems involved, and in the last few pages sums up its conclusions and recommendations, in which I concur, except so far as relates to the diversion to be permitted to be made by the Chicago Sanitary District. In respect to this, the trustees of the district have already been advised that the Chief of Engineers would not recommend to Congress any diversion greater than 250,000 cubic feet per minute, the limit set in the permit of the Secretary of War dated January 17, 1903, until the district had worked out and presented a suitable and comprehensive plan for treating its sewage so as to render it inoffensive and innocuous and at the same time reduce to a minimum the quantity of water necessary for its

dilution and transportation. This office has been informed that the sanitary district is now making the necessary studies and that plans based upon them will ultimately be presented for the approval of the War Department. Decision as to the diversion of the Chicago Sanitary Canal should therefore be deferred.

3. It is my understanding that the methods proposed by the division engineer and the Board for Rivers and Harbors for utilizing the water power of the Niagara River and for preserving the scenic beauty of the Falls are type plans merely. They show the results which can be secured but are not intended to be detailed or to prevent the adoption of any other plans which may appear preferable after such further study of the problems as may seem advisable when the work is finally authorized to be done.

4. Attention is particularly invited to the final paragraph recommending that all inclosures and illustrations, except Appendix I, be printed.

LANSING H. BEACH,
Major General.

REPORT OF BOARD OF ENGINEERS FOR RIVERS AND HARBORS.

[Second indorsement.]

BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
August 24, 1920.

To the CHIEF OF ENGINEERS, UNITED STATES ARMY:

1. This is a report by the division engineer of the Lakes division made in compliance with the provisions of public resolution No. 8, Sixty-fifth Congress, which reads as follows:

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That public resolution numbered forty-five of the Sixty-fourth Congress, approved January 19, 1917, entitled "Joint resolution authorizing the Secretary of War to issue permits for additional diversion of water from the Niagara River," is continued in full force and effect, and under the same conditions, restrictions, and limitations, until July 1, 1918: *Provided,* That the Secretary of War is hereby authorized and directed to make a comprehensive and thorough investigation, including all necessary surveys and maps, of the entire subject of water diversion from the Great Lakes and the Niagara River, including navigation, sanitary and power purposes, and the preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River, and to report to Congress thereon at the earliest practicable date. To carry out the provisions of this proviso, there is hereby appropriated, out of any money in the Treasury not otherwise appropriated, the sum of \$25,000.

2. The report is an exhaustive presentation of the facts regarding all existing diversions from the Great Lakes for navigation, for sanitation, and for the generation of power and of the effects of such diversions upon the levels and navigability of the Great Lakes and their connecting waters, as well as upon the scenic beauty of Niagara Falls and of the rapids of the Niagara River. In addition, diversions more or less seriously contemplated for one or more of the above three purposes are described and commented upon and measures for remedying damage already done, or likely to be done, both to the navigable capacity of the Great Lakes system and to the scenic beauty of the falls and rapids of the Niagara River are suggested.

3. The report is the only comprehensive and thorough investigation of all these subjects ever made and possesses great value not only from the technical, but also from the very full historical presentation of the matters with which it deals.

4. The most important features of the report are discussions of, first, the diversion of water from Lake Michigan through the Chicago Sanitary Canal; second, existing and proposed diversions from Lake Erie; third, present diversions for power purposes from above Niagara Falls, possible increases in these diversions, the utilization of diverted water to the greatest advantage and the works which will

neutralize or compensate for injurious effects of such diversions whether upon scenic beauty or upon the navigable capacity of the Great Lakes system; fourth, the possibility or advantage of combining the interests of navigation and of power production in a diversion into a navigable canal connecting the waters of Lake Erie and Lake Ontario; and, finally, the provisions of the existing treaty regarding boundary waters and suggestions of changes in and additions to it necessary to promote the interests of both the United States and Canada and to safeguard them more adequately.

5. In the following review of the report all existing or proposed diversions of whatever character from each unit of the Great Lakes system will be briefly described when the corresponding unit is under consideration, and thus disposed of finally. In the review and discussion, the nomenclature of the report of the division engineer is adopted, particularly in regard to the various types of plants for developing power from the Niagara River. As herein used, a "single-stage" water-power development is one in which water is conducted in a channel of some kind, whether artificial canal, tunnel, or vertical penstock, from the upper level in the Chippawa-Grass Island pool, at elevation about 560, to turbines set practically at the elevation of the lower Niagara River, about 248 feet above sea level, so that the total head due to the difference between the elevation of the Niagara River just above the Falls and its elevation at or near its mouth, some 310 feet, is developed in a single power house at about the latter level. A "two-stage" development is one in which the total head is developed in two power houses in series. The "upper stage" of a "two-stage" plant is that which corresponds to the head due to differences between the elevations of the Chippawa-Grass Island and the Maid-of-the-Mist pools, approximately 220 feet, and the turbines at this stage are set at the level of the latter pool, about 345 feet above sea level. The "lower stage" of a "two-stage" development is one in which the remaining portion of the fall of the Niagara River, namely, that which includes the Whirlpool and the Lower Rapids, and which has a head due to the difference between the elevations of the Maid-of-the-Mist pool and of the Niagara River at or near Lewiston, or about 90 feet, is developed in turbines set at about the latter level. The topographical conditions of the locality are such that a tunnel, from 2 to 3 miles long, is a necessary feature of this lower stage. The "compound two-stage" plan of the division engineer contemplates the development of the energy of a diversion of 20,000 cubic feet per second, with an upper stage in which the existing head-race canal and power station No. 3 of the Niagara Falls Power Co. diverting 10,000 cubic feet per second, are retained and augmented by a head-race tunnel, practically parallel to the canal and leading to a new power station practically in upstream prolongation of station No. 3. Both these stations would discharge into another tunnel which would lead the water to the turbines of the lower stage in a power house near the river level just above Lewiston. The "simple two-stage" plan discussed by the division engineer is one in which an entirely new diversion of 20,000 cubic feet per second is developed by means of two sets of turbines in series, a pressure tunnel from near Port Day on the Chippawa-Grass Island pool conducting the water to the turbines of the upper stage in a new power

house near the level of the Maid-of-the-Mist pool, about midway between the arched bridge at Niagara Falls and Suspension Bridge. These turbines would discharge into a pressure tunnel leading to a power station for the lower stage similar to that called for in the preceding plan.

REVIEW OF REPORT OF DIVISION ENGINEER, PARAGRAPHS 6-67, INCLUSIVE.

6. Diversions from the Great Lakes fall into three classes as concerns their effects. These classes are (a) those returned to the same body or level of water from which they are taken and which therefore do not affect water levels anywhere, and, doing no damage, require no limitation; (b) those which are restored to a lower level of the Great Lakes system and which reduce depths at and above the point of diversion, and all others downstream thereof to, but not including, the body of water into which they discharge; and (c) those which are permanently removed from the Great Lakes Basin, and lower water levels and do damage at and even upstream from the point of diversion, as well as at every downstream locality as far as tidewater.

7. There are no diversions from Lake Superior of sufficient consequence to justify mention. Small amounts of water are taken for the domestic purposes of some of the communities on its shores. Such small diversions find their way back into the lake and therefore do not influence its level even slightly.

8. Lake Superior discharges into the St. Marys River, which, as is well known, has been improved by both Canada and the United States, so that navigation may readily overcome the fall of approximately 20 feet which naturally exists there. The United States has built four large locks and there is one such lock on the Canadian side. In their operation, from 1,000 to 1,500 cubic feet per second is diverted during the season of navigation from the river through canals which conduct the water from the upper level to the locks. This diversion is, of course, necessary for the maintenance of a highly important navigation, but it is so small as compared with the discharge of the river that even though uncompensated, but little effect would be produced on the level of Lake Superior and of the river above the points of diversion. There are also three diversions from the St. Marys River for power development; one of these being in Canada and the other two in the United States. The aggregate diversion for power purposes is 43,000 cubic feet per second, which produces about 54,750 horsepower, as follows:

Present operation, Sault Ste. Marie power plants.

Plant.	Water used.	Power produced.	Horse-power.	Over-all efficiency.
	<i>Cubic feet per second.</i>	<i>Horse-power.</i>	<i>Cubic feet per second.</i>	<i>Per cent.</i>
United States Government.....	1,030	750	0.73	34
Michigan Northern Power Co.....	30,000	35,000	1.17	54
Great Lakes Power Co.....	12,000	19,000	1.68	73
Total, or weighted average.....	43,030	54,750	1.27	59

¹ Including 500 cubic feet per second wasted.

This diversion is nearly 60 per cent of the average flow of the river, which is 75,000 cubic feet per second, but its effects, and those of the diversions for navigation, are fully compensated by regulating works—a set of Stoney gates above the International Bridge. The control afforded by these gates is so complete that in addition to the diversions for navigation, 60,000 cubic feet per second may be used for power, while Lake Superior is ordinarily held between elevations 602.1 and 603.6 and its maximum range is restricted to 2.5 feet. Since 1860 the monthly mean stages of this lake have fluctuated between a low of about 600.50 and a high of 604.10, a range of 4.6 feet. Daily mean stages have, of course, shown a greater range, so that the regulating works are obviously beneficial to navigation. The advantage of developing all the water power possible is also plain, for the locality is a remote one and coal is expensive. The regulating works must affect the oscillations of the lakes below, but up to the present this effect has been slight and apparently no damage has been done to navigation.

9. In consequence of an act of Congress, one of the power plants on the United States side of the boundary was acquired by the United States in 1912. It is now operated by the Edison Sault Electric Co., under a lease by the Secretary of War, dated June 25, 1912. The legal status of this diversion calls for no further comment. The other power plant in the United States is that of the Michigan Northern Power Co., which was originally built in 1898–1902, under the terms of a permit issued by the Secretary of War, dated December 12, 1902. Its large diversion, amounting to 30,000 cubic feet per second, was the subject of considerable controversy which was finally settled by a lease executed by the Secretary of War, dated May 28, 1914.

10. Under this lease, the Michigan Northern Power Co. is permitted to take for a period of 30 years, beginning July 1, 1914, a continuous flow of water from St. Marys River above the rapids not to exceed a maximum daily aggregate at the average rate of 25,000 cubic feet per second of primary water, with not to exceed 5,000 feet of secondary water at such times as the level of Lake Superior and the flow of St. Marys River will permit, conditioned upon certain plant improvements and the construction of remedial and compensating works. A later lease, dated September 10, 1918, permits the use of an additional 3,000 cubic feet per second of water, referred to as excess secondary water, at such time as, in the opinion of the lessor, it is available.

11. A number of diversions for water supply are made from Lake Michigan and the city of Milwaukee uses about 1,000 cubic feet per second for flushing its harbor, but these are returned to the lake so close to the point of taking as to have no effect upon its levels. There are no diversions from this lake for navigation, and the only really significant diversion from it is that of the Chicago sanitary district. This diversion is primarily for sanitation, and the protection of the water supply of the city of Chicago, by preventing the discharge into Lake Michigan of the raw sewage of Chicago and the vicinity, under a plan whereby this sewage is intercepted, diluted, and transported into another drainage system, that of the Mississippi River, by way of the Des Plaines and Illinois Rivers, incidentally creating facilities for navigation and for the development of power.

This purpose is accomplished by reversing the flow of the Chicago and Calumet Rivers, naturally tributaries of Lake Michigan, which, through this change, become ordinarily parts of the Mississippi drainage system. The diversion through the Chicago Sanitary Canal averaged 8,800 cubic feet per second in 1917, although some daily averages were 10,000 cubic feet per second or more. Of this diversion, 6,800 cubic feet per second is incidentally used in the development of power, as will be explained later. Such small navigation as now exists would be amply served by a diversion of 500 cubic feet per second, and twice that amount would be sufficient for the needs of the greatest probable commerce of the so-called Lakes to the Gulf Waterway.

12. The Chicago Sanitary Canal diversion proceeds from Lake Michigan, whose normal elevation above sea level is about 580 feet, by way of the Chicago and Calumet Rivers through cuts excavated in the low divides which separate the lake drainage from that of the Des Plaines River, the two uniting in an artificial channel whose depth is over 24 feet and whose width varies between 160 and 202 feet. The Chicago River portion of the diversions begins at Robey Street in the West Fork of the South Branch, and for a length of 32.35 miles has practically the full canal dimensions above given. This portion of the canal was begun in 1892 and completed in 1900. The Calumet River diversion begins at Stoney Creek on the Little Calumet River and runs a distance of 16 miles through a shallow depression in the divide, called "The Sag," to a point on the main channel 3 miles above Lemont, the cut being in the form of a canal, which eventually is to be 22 feet deep and 70 to 90 feet wide. The main channel or canal is figured for a flow of 10,000 cubic feet per second, and the Calumet Canal for an initial flow of 2,000 cubic feet per second, to be enlarged ultimately to 4,000 cubic feet per second. The latter was begun in 1911 and is now nearly completed.

13. The Chicago Sanitary Canal was constructed without the sanction of Congress, and the only existing authority for this diversion is a permit of the Secretary of War, dated January 17, 1903, granting permission to divert 350,000 cubic feet per minute, or 5,833 cubic feet per second, during the closed season of navigation prior to March 31, 1903, and requiring reduction to 250,000 cubic feet per minute, or 4,167 cubic feet per second, thereafter. This permit was issued on the understanding that it was the intention of the Secretary of War to submit all pertinent questions connected with the sanitary district of Chicago to Congress. As yet Congress has taken no action, but meantime the sanitary district has for years greatly exceeded the limits of the permit of January 17, 1903.

14. In 1908 the Attorney General of the United States caused to be filed in the United States Circuit Court, Northern District of Illinois, a bill to enjoin the sanitary district of Chicago from constructing the Calumet-Sag Canal, and diverting through it the waters of Calumet River or Lake Michigan, thereby reversing the current in Calumet River, on the ground that these acts would impede and obstruct navigation and lower the level of Lake Michigan, thus impairing its navigability, all in contravention of section 10 of the river and harbor act of March 3, 1899. The real purpose of this suit was to assert the paramount authority of the United States over the diversion of the Chicago Sanitary Canal, and over all acts such as

would tend to injure the navigability or the navigable capacity of navigable waters of the United States. Testimony was taken in this case for about five years without reaching a decision. On October 6, 1913, the issue was more specifically raised in another bill filed by the Attorney General of the United States, praying that the defendant be enjoined from diverting more than 4,167 cubic feet per second from Lake Michigan through the Chicago River. The two suits were consolidated, heard as one, and, though the presentation of evidence and arguments of counsel had been completed in 1915, a decision had not been rendered at the time of submission of the division engineer's report; that is, about 12 years after the original bill had been filed.

15. There can be no doubt that a real need existed at Chicago for a remedy for the polluted state of its water supply and of the various streams near by that discharged into Lake Michigan. At the time the main sanitary canal was projected the art of sewage purification was in its infancy and a project so extensive as that of treating all the sewage and trade wastes of a population of over a million people had nowhere been seriously considered.

16. The remedy chosen by Chicago for the polluted state of its water supply and of its watercourses was, however, damaging to other interests. It is definitely known that the diversion of the amount of water authorized to be taken by the terms of the permit of 1903, namely, 4,167 cubic feet per second, at mean stages would lower the level of Lakes Michigan and Huron about 0.2 foot, of Lakes Erie and Ontario about as much, and of the St. Lawrence River at Lock 25 about 0.28 foot. The average diversion for 1917, 8,800 cubic feet per second, being uncompensated, has lowered the level of Lakes Michigan and Huron about 0.43 foot, of Lakes Erie and Ontario about 0.41 foot, and of the St. Lawrence River at Lock 25 about 0.57 foot. Damage, varying in amount with the locality, extends from the lower miter sills of the locks at Sault Ste. Marie through all the lakes and connecting channels to tide water in the lower St. Lawrence River, and its amount increases in the same proportion as the diversion at Chicago increases.

17. The dilution plan of the Chicago Sanitary District has not completely protected its domestic water supply. The uncertainty as to the quality of the water arises from the freshets of the Chicago and Calumet Rivers, which often exceed the volume of lake water diverted through the corresponding channels, the coincident temporary reversal of the currents of these rivers causing corresponding pollution of the lake. This condition is sure to increase with population and industrial activity unless the amount of the diversion is also largely increased, or unless steps are taken for the treatment of the sewage and trade wastes now finding their way into the two streams.

18. The report emphasizes the harm done by the Chicago Sanitary Canal in lowering the levels and diminishing the depths available for navigation from the lower sills of the locks at Sault Ste. Marie clear down to tidewater, but the division engineer feels forced to make some concession to the existing status of affairs, and he therefore, with evident reluctance, recommends that the Sanitary District of Chicago be authorized to divert not exceeding 10,000 cubic feet per second, conditioned upon supervision of the diversion by the

Secretary of War at the expense of the sanitary district, and upon the further stipulations that no dangers to navigation shall be caused by the diversion, that the district assume responsibility for all damages incident to the diversion, that it pay its due share of the cost of necessary compensating works, that it agree not to request or make any greater diversion, that it pay to the United States a tax or fee dependent on the additional amount of power that the diverted water could develop in the Niagara and St. Lawrence Rivers, and that it secure authority from the State of Illinois for the provision of works for sewage disposal other than by dilution and then provide such facilities as needed to care for the growth of its population.

19. While there are small diversions from Lake Huron for domestic water supplies in Canada and the United States which do not affect the level of the lake nor the volume of its discharge, there is one diversion from that lake worthy of mention. This is the Black River Canal, which extends from a point on the west shore of Lake Huron, about $1\frac{1}{2}$ miles north of the foot of the lake, westward about 1 mile to the Black River. From the canal junction the Black River flows $4\frac{1}{2}$ miles southerly through Port Huron to the St. Clair River, about $2\frac{1}{2}$ miles below the foot of Lake Huron. The sewage from a large part of Port Huron and the wastes from a sulphite pulp mill are discharged into the Black River. The canal was constructed by the city of Port Huron, without Federal permit, to flush Black River, which otherwise would be stagnant and insanitary. The canal has a bottom width of 25 feet with side slopes of approximately $1\frac{1}{2}$ on 1, the average depth is 6 feet, and the average fall about $1\frac{1}{4}$ feet. The diversion from Lake Huron averages 400 cubic feet per second, and lowers the lake about one-fourth inch. Though this diversion produces a negligible effect upon navigation, it is important in principle. No increase in it should be permitted.

20. Continuing downstream, except a number of diversions for domestic purposes which, as already explained, do not produce any hurtful effects, there are no diversions, existing or proposed, from the St. Clair River, Lake St. Clair, and the Detroit River, though there have been improvements of shoals in all three which might have tended to enlarge their capacity for discharge. Considering these three bodies of water as a unit, it may be said that its discharge capacity affects the levels of the two lakes above and of the St. Marys River to the lower lock sills. So far as can be judged, the works of channel improvement have been planned so as to give it liberal facilities for navigation, while at the same time the depths of the waterways and harbors above the improved localities have, by the exercise of proper precautions, been protected from damage, and there has been no effect of any kind produced below the mouth of the Detroit River.

21. There are numerous diversions from Lake Erie for domestic purposes, and these produce no hurtful effects either on Lake Erie or anywhere else. As already stated, the Chicago diversion has lowered Lake Erie about 0.41 foot, and there are two other diversions from the lake which have also reduced its levels. In addition, some of the diversions from the Niagara River have, as will be explained later, also lowered this lake.

22. The detrimental diversions from Lake Erie itself are the Welland Canal in Canada and the Black Rock Canal in New York.

23. The Welland Canal is $26\frac{1}{2}$ miles long, and extends from Lake Erie at Port Colborne, northward to Lake Ontario at Port Dalhousie. Its total drop from Lake Erie to Lake Ontario averages 326.35 feet, overcome by 25 lift locks and one guard lock. The locks are 270 feet long, 45 feet wide, and have 14 feet depth on the miter sills. The volume diverted from Lake Erie is approximately 4,500 cubic feet per second, and in addition it receives about 40 cubic feet per second from the Grand River, naturally a tributary of Lake Erie. Of these diversions, approximately 900 cubic feet per second is used for navigation, including lockage, leakage, and waste. Of the remainder, a very small amount is used for sanitary purposes, and the balance, about 3,300 cubic feet per second, for power development. At De Cew Falls there is a high head hydroelectric plant of good efficiency, owned by the Hamilton Cataract Power, Light & Traction Co., which has leases for the continuous use of 1,160 cubic feet per second, but appears to use about 2,100. The plant has a capacity of over 50,000 horsepower. The remainder of the water is used inefficiently at a large number of small developments having a combined capacity not exceeding 15,000 horsepower. There has been very little, if any, increase of diversion since May 31, 1910, the date on which the boundary waters treaty was proclaimed.

24. This canal is now being enlarged, partially along a new route. It is to have a total length of 25 miles, and the difference of elevation of Lakes Erie and Ontario is to be overcome by seven locks, each having a lift of $46\frac{1}{2}$ feet. The locks are to be 800 feet long by 80 feet wide in the clear, with 30 feet of water over the miter sills at extreme low stages in the lakes. The canal will have a bottom width of 200 feet, and for the present will be excavated to a depth of 25 feet only, though all structures will be sunk to the 30-foot depth, so that the canal can be deepened at any future date by dredging the reaches. Its operation is estimated to require a diversion of about 2,000 cubic feet per second, and the total diversion of the Welland Canal will then be about 5,300 cubic feet per second.

25. The Black Rock Canal is at Buffalo, N. Y., where it provides a waterway, with a modern lock adequate for the largest lake freighters, around the swift, shallow rapids at the head of Niagara River. The canal is formed by a wall or dike known as Bird Island Pier, extending from a point opposite the foot of Maryland Street, Buffalo, to the head of Squaw Island, about $2\frac{1}{2}$ miles, and by the passage between Squaw Island and the main shore. Within this area, which is $3\frac{1}{2}$ miles long and from 220 to 1,400 feet wide, is a dredged channel 21 feet deep and at least 200 feet wide. The Black Rock Lock has a usable length of 625 feet, usable width of 68 feet, and a depth of 22 feet on the miter sills at low stage. The diversion into the canal from Lake Erie is estimated to be about 700 cubic feet per second, of which 250 feet leaks back into the Niagara River through the dike, 400 is delivered into the head of the old Erie Canal, and the remainder is consumed in lockage. In the early days of the canal water power was developed at Black Rock, but this was discontinued many years ago. The 400 cubic feet per second now discharged into the Erie Canal partially flushes the sewage discharged into the abandoned portion of the canal between Buffalo and Tonawanda.

26. The Welland Canal affords the only navigable connection between Lakes Erie and Ontario and serves a traffic of 4,000,000 to

5,000,000 tons annually, of which about 10 per cent pertains to the United States. The Black Rock Canal affords a safe route for an important and growing tonnage and incidentally it gives access to the New York Barge Canal. Evidently the relatively small portions of these diversions that are used for navigation are necessary and valuable, and the treaty explicitly recognizes this fact by interposing no limitations upon diversions for navigation. The diversion for power purposes via the Welland Canal should, however, not be increased.

27. Both of these diversions lower Lake Erie and certain waters above and below it. For convenience, Tables 47 and 48, showing the effects of these and other existing and proposed diversions not only on Lake Erie, but on all other portions of the Great Lakes system are here reproduced, rendering needless further discussion of lowering effects, present and prospective.

TABLE NO. 47.—*Effect in feet of uncompensated diversions of water from the Great Lakes.*

Diversion.	Amount in cubic feet per second.	Michigan-Huron.			St. Clair.			Erie.		
		Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.
Chicago Drainage Canal	8,800	0.44	0.43	0.42	0.35	0.35	0.36	0.43	0.41	0.38
Welland Canal	4,500	.02	.03	.04	.08	.09	.10	.22	.21	.20
Black Rock Ship Canal	700	(¹)	(¹)	(¹)	.01	.01	.02	.03	.03	.03
New York State Barge Canal	1,000	(¹)	(¹)	(¹)	(¹)	(¹)	(¹)	.01	.01	.01
Niagara power companies	50,885	.01	.01	.02	.03	.05	.06	.10	.10	.11
Total lowering .....		.47	.47	.48	.47	.50	.54	.79	.76	.73

Diversion.	Amount in cubic feet per second.	Niagara River at Chippewa.			Ontario.			St. Lawrence River at Lock No. 25.		
		Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.
Chicago Drainage Canal	8,800	0.24	0.23	0.21	0.44	0.42	0.39	0.65	0.62	0.60
Welland Canal	4,500	.12	.12	.11	.....	.....	.....	.....	.....	.....
Black Rock Ship Canal	700	.....	.....	.....	.....	.....	.....	.....	.....	.....
New York State Barge Canal	1,000	.03	.03	.02	.....	.....	.....	.....	.....	.....
Niagara power companies	50,885	.63	.60	.57	.....	.....	.....	.....	.....	.....
Total lowering		1.02	.98	.91	.44	.42	.39	.65	.62	.60

¹ Inappreciable.

Lake Ontario has been raised about 0.56 foot by the construction of the Gut Dam, which is 50 per cent more than the lowering caused by diversions at Chicago.

Stages of the lakes referred to in this table.

	Michigan-Huron.	Erie.	Ontario.
Low	579.6	570.8	244.5
Mean	581.1	572.3	246.0
High	582.6	573.8	247.5

24 DIVERSION OF WATER FROM GREAT LAKES AND NIAGARA RIVER.

TABLE No. 48.—*Effect in feet at mean stage of proposed diversions from the Great Lakes.*

Diversion.	Proposed increase.	Lake Michigan-Huron.	Lake St. Clair.	Lake Erie.	Niagara River at Chippewa.	Lake Ontario.	St. Lawrence River at Lock 25.
Chicago Sanitary Canal.....	5,200	0.25	0.21	0.23	0.13	0.24	0.37
Welland Canal.....	1,000	.01	.02	.05	.03		
New York State Barge Canal.....	700			.01	.02		
Niagara Falls power.....	48,000	.03	.10	.22	1.25		
Total effect of proposed increases.....		.29	.33	.51	1.43	.24	.37
Total effect of present diversions.....		.47	.59	.76	.98	.42	.62
Sum.....		.76	.83	1.27	2.41	.66	.99

From these tables may be seen the lowering produced by these two diversions, the damage extending as far up as the lower sills of the Soo Locks and Lake Michigan and as far down as the Lower Rapids of the Niagara River.

28. A private company has for some time been proposing to construct between Lake Erie and Lake Ontario a waterway known as the Erie and Ontario Sanitary Canal, as a combined ship, sanitary, and power channel. The proposed canal would start from a new harbor south of Lackawanna, N. Y., on Lake Erie, terminate at Olcott, on Lake Ontario, and would have a length of 40 miles. At the east end of the proposed harbor in Lake Erie there would be a lock to lower vessels about 8 feet into the head of the canal. The route then runs along the eastern outskirts of Buffalo, through Hamburg, West Seneca, Cheektowaga, and Amherst Townships, crossing the New York State Barge Canal at grade in Pendleton Township. Passing through the west edge of Lockport Township it descends from the Niagara escarpment just west of "Lockport Gulf" by means of a pair of balanced lift locks, which would afford access to the "Ontario Plain," elevation about 351, the drop therefore being 209 feet. Another pair of balanced locks would overcome the remaining drop of 104 feet to the level of Lake Ontario near the mouth of Eighteen Mile Creek. It is proposed to divert through the canal 26,000 cubic feet per second, being the maximum amount allowed by the treaty with Great Britain for power with 6,000 feet additional for sanitation. This canal would lower Lake Erie an average of 1.18 feet, interrupt 83 railroad, electric railway and highway lines, and endanger the New York Barge Canal. The plan offers no advantages for either navigation or power, it is not regarded as economical or desirable for sanitary purposes, and construction is not recommended.

29. In leaving Lake Erie, the Niagara River falls with relative rapidity, the drop in the distance of 4 miles to the foot of Squaw Island being some 5.1 feet. From this point to a mile above the Welland River, a distance of about 17 miles, the fall is 4.8 feet, and then there follows a level pool called the Chippawa-Grass Island pool, about 2 miles long, whose average elevation above sea level is 563 feet. Below this pool are the cascades and rapids, which descend 50 to 55 feet, and lead to the two falls, the Horseshoe and the American, which drop, respectively, 162 and 167 feet into the Maid-of-the-Mist pool, whose average elevation is 343 feet, the difference

between the two pools thus being 220 feet. The Maid-of-the-Mist pool leads into the Whirlpool Rapids and the Lower Rapids with a combined fall of about 95 feet. The Lower Rapids terminate in the river near Lewiston, where the level is substantially that of Lake Ontario, average elevation about 245 feet above the sea. The only diversions now made from the Niagara River are above the Falls. Three are in the United States, three in Canada, and a fourth in Canada is in course of completion.

30. In the United States the diversion from the Niagara River furthest upstream is that of the New York State Barge Canal. It provides a waterway 12 feet deep, and not less than 94 feet wide, except at locks, from Buffalo on Lake Erie to the Hudson River at Waterford, and thence down the Hudson to New York City. The Champlain branch from Waterford to Lake Champlain is of like dimensions; as are also the short lateral branches at Rochester and Syracuse; the Oswego branch, connecting the main canal with Lake Ontario at Oswego; and the Cayuga and Seneca Canal, connecting the main canal with Cayuga and Seneca Lakes. It is 353.1 miles from Buffalo to Troy via the canal, and 153 miles from Troy to the Battery at New York City, or 506.1 miles from Buffalo to New York. The sole water supply for the western end to a point east of Rochester is obtained from the Niagara River at Tonawanda. The canal system was opened at the western end in midsummer of 1918. To date it is believed that the diversion has been somewhat less than the average amount assumed to be required ultimately, namely, 1,237 cubic feet per second. A portion of the water may be and is used for power development at Lockport, and to a smaller extent elsewhere along the canal, although this is a secondary use, the same water being required for navigation also. It is interesting to note that the barge canal causes a diversion into the Great Lakes Basin of about 50 cubic feet per second from the Mohawk River watershed, and another of about 35 cubic feet per second from the eastern headwaters of the Susquehanna River.

31. In addition to the diversion for navigation uses, there is now being diverted through the New York State Barge Canal from Niagara River approximately 500 cubic feet per second for power development at Lockport and along Eighteen Mile Creek. The quantity of water required for navigation, while figured to average 1,237 cubic feet per second, may, with increasing use of the canal, become considerably greater. The total developable head at Lockport and Eighteen Mile Creek is stated to be 286.5 feet. At Lockport there are three conduits or channels through which water may be by-passed around the flight of locks, from the upper level to the lower level of the barge canal. One supplies the plant belonging to the State, which is used for furnishing electric energy for lighting and operating the locks. The other two belong to the Hydraulic Race Co., the north tunnel producing 570 horsepower with 200 cubic feet per second under 50 feet of head, and the south headrace 3,078 horsepower with 773 cubic feet per second. At various spillways of the barge canal, power has been developed, partly from the spill and partly from the small streams passing under the canal in culverts. Along Eighteen Mile Creek there are a number of power plants, having a present total development of 4,694 horsepower, with 3,950 additional horsepower practicable.

Diversion data on Niagara Falls power plants.

	Diversion.	Power output.	Gross head.	Horse-power per cubic feet per second.	Overall efficiency.
	<i>Cubic feet per sec.</i>	<i>Horse-power.</i>	<i>Feet.</i>		<i>Per cent.</i>
Canadian Niagara Power Co.	9,600	100,000	173	10.4	53
Ontario Power Co.	11,200	183,000	215	14.6	60
Toronto Power Co.	12,400	125,000	183	10.1	49
International Ry. Co.	125	570	91	4.6	45
Hydroelectric power commission ¹	10,000	294,000	313	29.4	83
Niagara Falls Power Co.	9,450	100,000	219	10.6	43
Hydraulic Power Co.	7,840	145,000	219	18.5	² 76
International Paper Co.			219		
Pettebonne-Cataract Paper Co.	271	2,000	93	7.4	³ 70
Cataract Hotel.			24		

¹ Now under construction.² The Hydraulic Power Co. has three types of machines with widely different overall efficiencies, as follows: Station 2, 57 per cent; direct-current units in station 3, 77 per cent; alternating-current units in station 3, 81 per cent.³ Gross head taken at mouth of outfall.

37. By careful observation made during previous investigations at Niagara Falls, it has been found that diversions above them may affect the navigable capacity of the Niagara River, and the level of Lake Erie, and the waters above it, or they may affect only the scenic beauty of the Falls, including the rapids above and below, or injury may be done to both navigation and scenic beauty. The first cascade is a rock barrier with a clear, vertical drop of from 5 to 10 feet. It is thus a free overfall weir, and therefore the existing diversion below it in Canada of about 27,000 cubic feet per second produces no effect on the river above. The sole effect is to diminish the flow of the Canadian Rapids and of the Horseshoe Falls, thereby helping to expose more of the crest at each end, undoubtedly a very serious injury to the harmony and beauty of the spectacle, while only slightly, if at all, affecting the rapids above the Falls. Except the small diversion of the barge canal, all the existing Canadian and American diversions from the Niagara River discharge into the head of the Maid-of-the-Mist Pool, and therefore produce no effect of any kind below their outlets.

38. Diversions from the Chippawa-Grass Island pool damage the scenic beauty of the Falls in precisely the same manner as do the diversions below the cascades, and additional similar damage is done by the diversions at Chicago, and through the Welland Canal, the total of all these diversions being at present about 66,000 cubic feet per second.

39. The division engineer presents photographs to show that the diversions for power affect the appearance of the American and Canadian Rapids and the American and Horseshoe Falls, but not of the Whirlpool Rapids or of the Lower Rapids. One set shows conditions at extremely high stage, one at about mean stage, and one a little below mean stage. Prior to the submission of the main report there had been no opportunity for obtaining views at extremely low stage. Subsequently, on April 22, 1920, an unusually low stage of Lake Erie occurred, and it became possible to obtain a set of views of the Falls with a discharge of only about 135,000 cubic feet per second. These views accompany the supplemental re-

port dated May 19, 1920, and show the detrimental effects of low Lake Erie stages, and correspondingly low discharges on the scenic beauty of the Falls in their natural condition. The effects of stage upon the scenic beauty of the Falls and the rapids above and below are summarized in the report as follows:

1. The American Rapids are not much affected by stage, but look best with a moderately large flow.
2. The Canadian Rapids are very little affected by stage except the northwest corner, which require an extremely high stage to cover the shoal there.
3. The American Falls look best at high stage.
4. The "notch" of the Horseshoe Falls is of small scenic value at any stage. At low stages it is more often visible because there is then less mist.
5. The ends of the Horseshoe Falls look very poor at low stage, and poor enough at the ordinary conditions now prevailing. At very high stages they are marvelously improved.
6. The Maid-of-the-Mist Pool and the Whirlpool derive their beauty primarily from the gorge, not the river, and are not affected by change of stage.
7. The Whirlpool Rapids and Lower Rapids are at their best at a comparatively low stage. As the flow increases much of their attraction is lost.

40. The various power companies at Niagara now divert over 50,000 cubic feet per second around the Falls and into the Maid-of-the-Mist pool. In addition, the New York State Barge Canal, the Welland Canal, and the Chicago Drainage Canal are taking some 12,000 or 13,000 cubic feet per second which would otherwise flow over the Falls and through the Gorge. In the near future, when the new Welland Canal is put in operation and the plants now under construction at the Falls are finished, the total diversion affecting the Falls will be nearly 70,000 cubic feet per second. The effect on Horseshoe Falls of the existing diversions will be seen from an examination of photographs Nos. 89 and 99, the former taken with a river discharge of 212,000 cubic feet per second and the latter with a discharge of 274,000 cubic feet per second. It seems clear that the scenic beauty of Niagara Falls has been appreciably damaged both by the recession of the apex of the Horseshoe Falls, which is proceeding at a rate of about 4 to 6 feet a year, and by the diversion of water for power and other purposes. At the present time there flows over the central 600 feet of the Horseshoe Falls a volume of approximately 80,000 cubic feet per second, which not only is entirely wasted in that it creates neither scenery nor power, but which is actually the cause of destructive erosion producing the recession referred to. If means were adopted to distribute the flow evenly over the Falls, a much greater diversion than the present could be allowed without injury to the scenic effects.

41. The remedial works proposed to improve scenic conditions at Niagara Falls by the division engineer contemplate the following: That the high Canadian end of the Falls and the shoal south of it should be cut down by excavation made in cofferdams; that the high places near Terrapin Point and to the south should be similarly excavated in another cofferdam; that to distribute the flow more uniformly a submerged weir, curved in plan, should be built across the central part of the rapids a short distance upstream from the "notch" of the Horseshoe Falls; and that the American channel should be given a flow of 12,000 cubic feet per second by means of a submerged compensating dike extending from Goat Island to Chippawa. It is believed by the division engineer that the cost of remedial works should be equally divided between the United States and Canada.

42. If these works are constructed, the division engineer believes that then a considerable addition to diversions from above the Falls is not only permissible but desirable. At present, the greatest detriment to the beauty of the Horseshoe is the prevailing mist, and the constant recession of its crest is an ever-present and growing menace not only to the appearance of the Horseshoe but also to the permanence of the water supply of at least one of the power companies. The greatest volume that can be taken consistent with maximum attainable scenic beauty is that which will reduce the obstructive mist to a minimum while at the same time insuring adequate ice discharge capacity. With the flow approximately uniformly distributed over the crest of the Horseshoe, this maximum diversion from the Niagara River above the Falls is put at about 80,000 cubic feet per second.

43. The table in paragraph 36 shows the very great difference that exists between the efficiencies of the various power plants at Niagara Falls, the range being between 43 and 75 per cent, while 83 per cent is predicted for the Chippawa-Queenston development of the Hydroelectric Power Commission. The efficiencies stated for the existing power stations relate only to the head actually developed, 220 feet more or less, and therefore ignore the now undeveloped head of 90 feet or more. To this extent, these efficiencies are not properly comparable with that predicted for the Chippawa-Queenston development. In any event, the importance to society of developing the greatest possible amount of power from the volume of water permitted to be diverted is evident and the division engineer lays down the rule that future developments should have an overall efficiency of more than 80 per cent, and produce over 20 horsepower per cubic foot per second if they discharge into the Maid-of-the-Mist pool and over 29 horsepower if the discharge is into the river near Lewiston. These figures may well be contrasted with the present development of 635,570 horsepower, with a diversion of over 50,000 cubic feet per second and an average of only 12.5 horsepower per cubic foot per second. Each additional horsepower developed by these diversions is when continuously used worth at least \$30 annually to a consumer who would otherwise be forced to use steam power. The greater the efficiency of development the cheaper the power may be sold.

44. Diversions from the Chippawa-Grass Island pool, by lowering the pool itself and increasing the slope between it and the upper river, also lower Lake Erie and the waters above it. The three diversions from the Chippawa-Grass Island pool, consisting of about 6,000 cubic feet per second in Canada and 17,000 cubic feet per second in New York, a total of 23,000 cubic feet per second, lower the pool about 0.6 foot and increase the discharge from Lake Erie by about one-tenth of the amount of this diversion, thereby lowering that lake about one-tenth foot. The small diversion for navigation and power through the barge canal is also made from the Chippawa-Grass Island pool and has proportionately a similar effect in lowering the pool and Lake Erie. The amount by which the various portions of the Great Lakes are affected is shown in Table 47.

45. The diversions from the Niagara River cause diminished depth in many harbors and in the connecting channels, which limit the draft to which the bulk freighters of the Great Lakes may load. Using data based upon conditions existing at the time of his report, the division engineer figures that each tenth of a foot of draft cor-

responds to freight earnings of \$44.57 per trip. With an average of 25 trips per season, he estimates that the fleet of large bulk freighters plying Lake Erie and the waters above loses \$590,000 annually for each one-tenth foot reduction in permissible draft, while the corresponding loss for the smaller vessels using the Welland and St. Lawrence Canals is about \$70,000. The total loss in both trades due to all existing diversions is estimated to have been \$4,713,000 in 1917.

46. The plan of the distributing weir and other work for remedying the damage already done to the Horseshoe and for improving its appearance has already been sufficiently described. The detrimental effect upon navigation of diversions from the Niagara River is also susceptible of being remedied by appropriately designed and located works of simple and relatively inexpensive character.

47. The division engineer proposes to restore depths available for navigation by the submerged weir near the foot of the Chippawa-Grass Island pool, and by two sets of submerged weirs, one near the head of the Niagara River, the other near the head of the St. Clair River, to raise the levels of Lakes Erie, Huron, Michigan, and their connecting and tributary waters. The effect would be to restore the waters above named to the levels they would have had before any diversions were made. After their completion, these lakes will discharge through all their outlets the same quantities of water that they formerly discharged when the same stage naturally prevailed. In other words, compensation will then have been made for damage done, but the variations in lake stages and discharges will go on as before.

48. A plan for raising the levels of Lake Erie and of the system above it so as to afford greater depths for navigation was presented by the Deep Waterways Board in its report of June 30, 1900, and provided for the regulation of Lake Erie between the levels 574.2 and 574.8, thereby raising the mean level between 2 and 3 feet. Lake St. Clair would, it was estimated, be raised about three-fourths and Lake Huron one-third as much. These works consisted of a length of 2,900 feet of submerged weir in two sections and a series of 13 sluiceways, 80 feet wide and 23 feet deep, provided with Stoney gates. They would compensate for the lowering effects of diversions considerably greater than now exist. The division engineer points out certain objections to this plan, which are hereafter discussed.

49. A second plan, proposed by the International Waterways Commission in 1913, consisted of a long fixed weir from above the mouth of Welland River to Gill Creek, raising the Chippawa-Grass Island pool 3 feet and Lake Erie about 4½ inches. This plan would afford incomplete compensation for existing diversions. Another plan for intermittent regulation to control discharge and to furnish better navigation during the open season has been presented to the board by the sanitary district of Chicago, and is here described simply to render the discussion more complete. It contemplates the construction of a longitudinal division wall in the Niagara River nearly a mile below the site of the works planned by the Deep Waterways Board, and about 2 miles below the main entrance to Buffalo Harbor. Here the river is about 1,800 feet wide. The wall will divide it into two channels, respectively, 800 and 1,000 feet wide. The narrower or American channel is to be used for regulation, the wider

channel to remain open. The gates proposed are daring in design, being removable, ship-like caissons about 200 feet long with butterfly valves, for which emplacements or anchorages are provided in the bed of the river. Four such gates are proposed to be floated to place and anchored in May and removed in December. In place, with all valves closed, they are figured to reduce the discharge about 40,000 cubic feet per second. The function of these works is stated by their designer to be as follows:

First. The creation of a higher mean Lake Erie level of about 13 inches over the level which would obtain during the continuous diversion of 10,000 cubic second-feet at Chicago.

Second. The negative function of maintaining a substantially unimpaired outflow capacity for the Niagara River for water and ice during the winter season, and at times when the lake tends to crest at elevations approaching 574 and flood heights need to be avoided.

Third. The throttling, when desirable, of perhaps 40,000 cubic feet per second when the supply warrants the saving of water for later release to equalize the flow.

Fourth. The ability to release during certain hours of the day a volume of 30,000 cubic second-feet of impounded water.

It will be observed that this plan would raise Lake Erie considerably more than the amount it is lowered by the existing diversion at Chicago and by all other diversions now made, and that liberal margin would be left for an increase in diversions.

50. Contingent upon the construction of the remedial and compensating works proposed by him, the division engineer believes that a total of 80,000 cubic feet per second may be diverted from above the Falls, which should be equally divided between Canada and the United States, and that of this total 40,000 cubic feet per second should be returned to the Maid-of-the-Mist pool, this latter condition being for the protection of the scenic beauty and ice discharging capacity of the river below the Falls.

51. The report furnishes an extended discussion of the details and merits of the existing power plants at Niagara Falls and of the best—that is, the most economical or efficient—plan for utilizing the existing diversion and any additional one, including the advisability of joint use for navigation and power production.

52. As already mentioned, there are at present three American diversions from the Niagara River for power purposes. These include a diversion of 500 cubic feet per second through Tonawanda Creek and the New York State Barge Canal for use by power plants at Lockport, N. Y. This is about a century old and therefore was in existence at the time cognizance was first taken by the United States of the harmful possibilities of diverting water from the Niagara River. The use of this diverted water at and below Lockport appears to be inefficient.

53. The other two diversions are made just above the Falls near Grass Island and Port Day. The upper diversion, that of the original Niagara Falls Power Co., is reported as 9,450 cubic feet per second, from which about 100,000 horsepower is developed. This company was the pioneer in developing water power and generating electricity upon a large scale at Niagara Falls. Its operations were begun about 1890, when the art was in its infancy and there appeared no possibility of limitations on the use of water. The plant consists of two power houses fed by a short headrace canal discharging into

penstocks which conduct the water to turbines installed at the bottom of deep pits, the draft tubes of the turbines connecting with a tailrace tunnel having considerable slope and opening into the Maid-of-the-Mist pool just below the highway bridge at Niagara Falls. Judged by present standards, the plant is not efficient, its output of 10.6 horsepower per cubic foot-second corresponding to an over-all efficiency of only 43 per cent.

54. The remaining American diversion is that of the former Hydraulic Power Co., which is reported as diverting at Port Day about 8,110 cubic feet per second into a headrace canal nearly a mile long leading to penstocks conducting the water to two power houses in the Gorge below the highway bridge practically at the level of the Maid-of-the-Mist pool. These plants produce 145,000 horse power, an average of 17.9 horsepower per cubic foot-second, when the diversion made from the canal by the Pettebone Cataract Power Co., amounting to 271 cubic feet per second, is included, and of 18.5 horsepower per cubic foot-second when the latter diversion is not considered. The latter corresponds to an over-all efficiency of 75 per cent, and the efficiency is about 72 per cent when the whole diversion is considered. The company is enlarging its canal and building an extension of station No. 3, which will hold three units of about 37,500 horsepower each and will use probably slightly over 5,000 cubic feet per second, with a claimed efficiency of close to 85 per cent. (This enlargement has since been completed, the three new units are operating, and the total diversion into the canal is now over 10,000 cubic feet per second.)

55. The two power companies above mentioned have recently been combined under the name of Niagara Falls Power Co. With the three new units above mentioned in operation it will, under existing treaty limitations, be necessary to discontinue the operation of some of the less efficient units so as to keep the total power diversion at 20,000 cubic feet per second. The division engineer presents a plan for developing the energy of this diversion with maximum efficiency. He calls this the compound two-stage plan. Under it station No. 3 of the Niagara Falls Power Co. is retained, and the remainder of the diversion is to be taken through a pressure tunnel virtually parallel to the hydraulic canal to what is really an extension of station No. 3, thereby developing about 409,000 horsepower from the first stage, whose head is 220 feet. The tail water then discharges into a tunnel which leads the water under pressure to a power house near Riverdale Cemetery in the lower Gorge, where 160,000 horsepower additional is developed from the head of 90 feet available in the second stage.

56. On the assumption that it may be possible to take 20,000 cubic feet per second additional in the United States, plans are presented for utilizing this water in three types of installations for developing the total head of about 320 feet, and in a single type of installation in which the head is developed in two stages taking all the water first by a pressure tunnel to a station well down in the Maid-of-the-Mist pool under a head of 220 feet and then through a second pressure tunnel under the head of about 90 feet to a station in the lower Gorge at the same site as in the compound two-stage plan.

57. It is advisable to call particular attention to the statement in paragraph 92 of the report that the estimates do not include the entire capital costs, nor the whole of the construction costs. Costs of promotion, of raising funds, of organization, and of legal services are omitted as are also the cost of purchasing any legally enforceable rights now belonging to any existing companies. The development expense in building up a market for power is also omitted. The omission of any allowance for existing investments particularly affects the estimate for the "compound two-stage" plan in which the output of the existing plants is included without payment, so that the estimated unit cost of \$51.80 per horsepower for this plan is lower than the actual cost would be to anybody who had to pay for property or rights already in existence, or who had already paid for such rights or property.

58. The division engineer's conclusion is that a combined power and ship canal which, under the topographical conditions, should be built along the La Salle-Lewiston line, would be less economical than a ship canal along this line and a separate power canal from the vicinity of Conners Island to the Gorge at Riverdale Cemetery. The estimated cost of the combined plan is about \$200,000,000, while the separate ship canal would cost \$135,000,000 and the separate power development about \$46,000,000, the difference in favor of the separate canals being about \$19,000,000. The combined canal is to have 12,000 square feet area of cross section, being alternately 300 by 40 feet and 400 by 30 feet, while the separate navigation canal is to be of 6,000 square feet area of cross section or 200 by 30 feet. For the development of a new diversion of 20,000 cubic feet per second in a single stage, he discusses plans producing about 600,000 horsepower with practically equal efficiency, first, by means of a plant consisting of a power house near Conners Island placed in a deep pit and discharging into a tailrace tunnel with the surface of tail-water substantially at the level of the lower Niagara River, about elevation 248; second, by a pressure tunnel starting at nearly the same point in the Chippawa-Grass Island pool and leading to a power house in the lower Gorge near Riverdale Cemetery, and, third, by means of a canal leading to a power house at the same location. His estimates of the construction cost per horsepower on the bus bar, under the assumptions made by him, are \$89.40 for the first plan, \$86.40 for the second plan, and \$73.70 for the third plan. He believes that the tailrace tunnel plan involves construction difficulties due to the possibility of encountering ground water at the low level of the tunnel, and that both this plan and the pressure tunnel are liable to difficulties in operation, such as surges in the tailrace tunnel, dangers from ice, necessity of unwatering for repairs to valves, et cetera. His only objections to the canal plan are that there may be some ice difficulty and that the canal will cut through valuable land and interfere with highways, railways, water supply and sewage systems, as well as, perhaps, with the most economical development of adjacent real estate.

59. For an additional diversion of 20,000 cubic feet per second by the simple two-stage plan, he estimates the total output to be 580,000 horsepower, at a cost of \$105.60 per horsepower. This cost is greater than under any of the single stage plans, and more than half of the

total cost belongs to the second stage which furnishes only about 160,000 horsepower out of the total of 580,000. It is plain that the division engineer believes that a second diversion of 20,000 cubic feet per second should preferably be in a single stage, thereby making the most economical use of the water that may safely be completely diverted from the Maid-of-the-Mist pool.

60. On the basis of these construction costs, the division engineer figures that the cost on the bus bar will be \$10 to \$13.90 per annual horsepower for the new diversion of 20,000 cubic feet per second, while if only one such amount is to be diverted and existing rights are valid and therefore must be paid for, these figures are increased to from \$14.90 to \$17, the cheapest development in every case being the single stage power canal.

61. There are numerous diversions for domestic purposes from the Niagara River and Lake Ontario, as well as from the St. Lawrence, but as these are immediately returned they produce virtually no effect upon levels. There are, however, no diversions for navigation either from the lower Niagara or from Lake Ontario.

62. Existing diversions from the St. Lawrence River above St. Regis are utilized for both navigation and water power, and include four lateral canals constructed by the Dominion of Canada, known as the Galop Canal, Rapide Plat Canal (also called the Morrisburg Canal), Farran Point Canal, and the Cornwall Canal. The diversions are small, and in each case the water is returned to the river. The diversion by the Galop Canal is between 500 and 1,000 cubic feet per second, of which an average of 200 or less is used for navigation and the remainder for power. The diversion by the Morrisburg Canal is between 1,000 and 1,500 cubic feet per second, of which possibly 200 feet is required for navigation and the remainder for power. The Farran Point Canal diverts about 50 cubic feet per second, all for navigation. The diversion by the Cornwall Canal is about 3,000 cubic feet per second, of which possibly 300 only is required for navigation purposes. These canals were built primarily for the benefit of navigation, and are open for use equally by the vessels of both countries. The development of water power along these canals was originally a secondary and incidental matter, although much of the water is now diverted solely for that purpose.

63. The St. Lawrence canals accommodate vessels 255 feet long, 42 feet beam, and drawing 14 feet. The river is closed by ice for an average of 144 days per annum, from about December 3 to about April 27.

64. In addition to the above-mentioned diversions primarily for navigation, there are two developments solely for water power. These are the Massena Canal, on the United States side of the river, at the head of Long Sault Rapids, and the development at Waddington, N. Y. The Massena Canal extends about 3 miles from the St. Lawrence to a power house on the Grasse River, a tributary of the St. Lawrence. It has a bottom width of 188 feet and a depth of 25 feet. There is a head of about 43 feet at the powerhouse, for which the Grasse River serves as a tailrace, conducting the water back to the St. Lawrence at a point 10½ miles downstream from the point of diversion. Until recently the quantity of water diverted was approximately 30,000 cubic feet per second, developing a

maximum of 80,000 horsepower. Due to improvements undertaken during the war, an output of 60,000 horsepower is now produced with a consumption of only 17,000 cubic feet per second. At Waddington, N. Y., a dam 950 feet long was constructed more than 100 years ago across the American channel. The flow through the American channel, known as Little River, is estimated to be 3,000 to 4,000 cubic feet per second, of which about 600 cubic feet is used intermittently and inefficiently in the development of power. A small powerhouse is located at the downstream side of the dam, and a power canal 15 to 20 feet wide leads from the south end of the dam downstream along the bank of the river for about 950 feet, serving four plants. The company owning the rights at this locality has proposed the construction of a new plant to develop 30,000 horsepower, with the use of about 30,000 cubic feet per second.

65. The problem of how the development of power may best be combined with the improvement of the St. Lawrence for navigation is, as stated by the division engineer, at present under consideration by the International Joint Commission. It is not, therefore, advisable to discuss further such plans as have hitherto been proposed for diverting water from the St. Lawrence.

66. Finally, the division engineer discusses the existing boundary waters treaty with Canada, and recommends that it be amended so as to cover the existing needs and anticipate future requirements more satisfactorily and with more flexibility.

67. The recommendations of the division engineer regarding modifications of the treaty and the use of diversions are as follows:

Recommended treaty provisions.—It is recommended that the treaty with Great Britain proclaimed May 13, 1910, be modified in the following particulars:

(1) That the wording of the treaty be altered to extend the jurisdiction of the International Joint Commission to include diversions from tributaries of boundary waters except in the case of diversions from a tributary which are returned to the same tributary.

(2) That the words, "the scenic beauty of the Falls and Rapids," be inserted in the first sentence of Article V after the word "Erie."

(3) That the diversion of water from Niagara River below the Falls be specifically limited in the same manner as the diversion from the Niagara River above the Falls.

(4) That the treaty provide for the construction and maintenance of remedial works of the nature outlined in section (e) of this report; such works to be built under the supervision of the International Joint Commission, or of some other international body created for the purpose; the remedial works to be so designed and constructed that the scenic beauty of the Falls will be restored and preserved when 80,000 cubic feet of water per second is diverted from the Niagara River above the Falls; the expense of constructing and maintaining said works to be borne equally by the high contracting parties.

(5) That the limits of diversion from the Niagara River above the Falls, which the high contracting parties may permit within their respective jurisdictions, be raised from 20,000 cubic feet of water per second on the United States side to 40,000 cubic feet of water per second and from 38,000 cubic feet of water per second on the Canadian side to 40,000 cubic feet of water per second.

(6) That 20,000 cubic feet per second of the water so diverted upon each side of the river shall be returned to the Niagara River at some point or points upstream from turning point No. 134 of the international boundary line adopted August 15, 1913, by the International Waterways Commission under Article IV of the treaty between the United States of America and the United Kingdom of Great Britain and Ireland signed April 11, 1908; and that if any part of the remaining diversion be returned to the Niagara River at any point an equal or smaller amount may be again diverted from any point farther downstream.

(7) That the limits given above be stipulated to apply to the amount actually diverted at any instant, and that accordingly the words "in the aggregate" and "daily" be stricken out of Article V of the present treaty wherever they occur; that it be recognized that small, brief, accidental violations of the provisions of a diversion permit must be allowed if the holder of the permit is to obtain the full value thereof, and that therefore such violations shall be permitted under such regulations as the International Joint Commission shall provide.

(8) That five years after the completion of the remedial works the International Joint Commission, or some other body constituted for the purpose, shall inform the high contracting parties whether or not, in its opinion, further diversions of water from the Niagara River for power development can be made, either continuously or intermittently, without serious injury to the scenic beauty of the Falls and Rapids, the integrity of the river as a boundary stream, or appreciable lowering of lake levels. That, if this opinion be favorable to the further diversion of water, the commission or body shall indicate the amount of further diversion which may properly be allowed, and the conditions by which permits should be limited.

Recommended use of diversions.—In regard to the use of the various diversions of water from the Great Lakes and Niagara River, the following recommendations are made:

(1) That no change be made in the method of dealing with diversions whose primary use is for navigation purposes.

(2) That Federal control of the diversion at Chicago and in the vicinity be established by such measures as are necessary, provided the United States Courts do not uphold the present apparent right of the Federal Government to regulate the diversions there; the Sanitary District of Chicago being permitted to divert from Lake Michigan and its tributaries a total quantity of water not exceeding at any time a flow of 10,000 cubic feet per second; under the conditions that the Secretary of War shall supervise the diversions as he deems best, that the expense of supervision shall be paid for promptly at stated intervals by the Sanitary District of Chicago, that no dangerous conditions shall be created in navigable waters, that the sanitary district agrees to be responsible for any damage claims arising because of the diversion, that it shall pay its share as determined by the Secretary of War of the cost of such compensating works as the Federal Government considers necessary because of diversions of water from the Great Lakes system, that it agrees not to request or make any diversion in excess of that herein stated, that it shall pay to the United States for water used for power purposes at a rate per cubic foot to be based upon the relative value of the power as developed and that which could have been developed by its use at Niagara Falls, N. Y., and along the St. Lawrence River, and that it does all in its power to secure any State authority needed to enable it to undertake the establishment of provisions for sewage disposal other than by dilution and when so enabled provides as rapidly as necessary such sewage disposal facilities as are needed to care for the growth of the district.

(3) That consideration be withheld on all proposals for water diversions for combined navigation, power, and sanitary purposes unless of far-reaching importance and effects and consistent with plans approved by the International Joint Commission as remedial against the pollution of boundary waters.

(4) That the present method of controlling the power diversions at Sault Ste. Marie be not disturbed.

(5) That the total diversion through the Welland Canal for power development be limited strictly to the present amount.

(6) That the diversion through the New York State Barge Canal for power development be limited to the 500 cubic feet per second now allowed.

(7) That as soon as a treaty has been negotiated with Great Britain along the lines indicated in section (k), additional permit or permits be granted so as to make the permitted diversion from Niagara River above the Falls on the United States side 40,000 cubic feet per second, one-half of which is returned to the river in the Maid-of-the-Mist Pool.

(8) That the Secretary of War, the International Joint Commission, or a special board of engineers be requested to prepare plans and estimates in detail for a comprehensive system of compensating works for restoring the levels of all the lakes and their outflow rivers, these plans to be submitted to the International Joint Commission for approval, with the intent that such works be constructed and paid for jointly by the United States and Canada.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS OF THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS, PARAGRAPHS 68-129, INCLUSIVE.

68. On June 4, 1920, the Board of Engineers for Rivers and Harbors held a widely advertised and numerously attended public hearing at Niagara Falls, N. Y., for the purpose of affording to all concerned or interested a full opportunity for the discussion of diversions from the Great Lakes and general principles that should be observed regarding their limitations and utilization. A transcript of the stenographic notes of this hearing is appended hereto, together with copies of exhibits then filed by certain of the interested parties. In addition, on July 27, 1920, the board gave a special hearing to Mr. T. Kennard Thomson, who had been unable to attend the public hearing at Niagara Falls. Mr. Thomson is the advocate of the plan for damming the Niagara River at Fosters Flats, and his arguments in favor of this plan, having been fully heard, are given due weight in the conclusions that follow. Finally, on August 3, 1920, the board gave another special hearing to Mr. Charles A. Pohl, who presented arguments against the "compound two-stage" plan and in favor of a direct diversion from the Maid of the Mist pool, on behalf of the Niagara Gorge Power Co., and to Col. H. L. Cooper, whose arguments were based upon the large general aspects of the diversion problem and the manner in which it should, in his opinion, be treated. The board has, of course, given consideration to these arguments and to all other evidence that has come to its notice.

69. Public resolution No. 8, Sixty-fifth Congress, which directed the making of this investigation, reads in part as follows:

Provided, That the Secretary of War is hereby authorized and directed to make a comprehensive and thorough investigation * * * of the entire subject of water diversion from the Great Lakes and the Niagara River, including navigation, sanitary and power purposes, and the preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River.

The division engineer—and, in our opinion, correctly—believes that it was the desire of Congress not only to be advised of the facts regarding all diversions for the above purposes but also to secure information and recommendations upon which to base a just policy as to present and future diversions for any or all of the purposes enumerated; and it was further the obvious wish of Congress that any such permanent policy should give due weight to the importance of the scenic beauty of Niagara Falls and the rapids.

70. At the time of the passage of the resolution Congress already knew that many of the diversions then in existence were productive of damage, both to navigation and to scenic beauty, but, as all diversions were to a greater or less degree useful or beneficial to those who were making them, there was difficulty in fixing their relative merits. The report now enables this to be done with confidence and reasonable certainty, and thereby to arrive at the details of the policy apparently desired by Congress. We shall therefore briefly discuss the three kinds of diversions mentioned in the resolution, as well as the preservation of scenic beauty, give our opinion as to their relative importance and as to the permissible limits of the three varieties of diversions, and finally state our views as to the orderly steps that should be taken in the execution of what we regard to be the proper policy with respect to diversions and scenic beauty.

71. In advance of the more detailed discussion we may say that we believe that navigation purposes in value and importance take precedence over all other uses to which the waters of the Great Lakes may be put. As a first step in a proper policy, damage already done by diversions should be remedied by the adoption of some plan that will not only restore losses of depth but also increase lake levels so as to afford higher stages than would naturally exist. The plan for accomplishing these purposes with a maximum of certainty and benefits, both direct and indirect, is the construction of a regulating dam provided with sluiceways at the head of Niagara River which would restore and increase depths in Lakes Erie, Huron, and Michigan and their connecting waters, and in the St. Marys River below the locks, and at the same time permit the discharge of the Niagara River hereafter to be made nearly uniform, thereby increasing by 20 per cent or more the natural low-water discharges which have a determining influence on the scenic beauty, power development, and navigation and therefore serve to indicate the maximum diversions that may be made from the Niagara River. On the other hand, there should be no limitation on the diversion of water actually needed for the supply of navigation canals, and no difficulty will be experienced in remedying the losses of depth caused by the small diversions of this kind.

72. Diversions of water for "sanitary purposes" include those made by municipal water-supply and sewage systems and, except in the cases of Chicago and Port Huron, the quantities taken are always insignificant, and, as they are immediately restored practically undiminished to the source from which they are derived, the diversions do no damage either to navigation or scenic beauty, and they therefore call for no restriction. The United States should, however, do everything in its power to disseminate knowledge as to the pollution of the Great Lakes and to promote the adequate treatment of drinking water and of sewage.

73. The diversions for "sanitary purposes" at Chicago and Port Huron do not, however, return the water immediately to its original source. At Chicago the water is diverted to an entirely different drainage basin, the Mississippi, and the Great Lakes are therefore deprived of this much of their natural supply. At Port Huron the Black River Canal takes the water from Lake Huron and discharges it into the St. Clair River some distance below Lake Huron. The diversion is small and its effect correspondingly so. Were it larger it might be sufficiently detrimental to justify further notice. As it is, the Port Huron diversion may be tolerated but it should not be increased, while the Chicago diversion is so large and its effects so important that more positive measures are necessary, the details of which will be given hereafter.

74. There are numerous diversions for "power purposes" on the Great Lakes and the Niagara River and the St. Lawrence. Cheap power is obviously desirable and development of water power should therefore be encouraged so far as is consistent with the more important or desirable interests of navigation and scenic beauty that it is the public duty to notice and to safeguard. This is the only limitation upon the diversion of water for "power purposes" that we recommend. At Sault Ste. Marie practically the entire river is diverted for "navigation purposes" or for "power purposes." Evi-

dently nothing should be taken for power until navigation has been adequately supplied and until the danger of lowering Lake Superior has been adequately overcome. As the regulating works above the International Bridge actually hold Lake Superior at higher stages than would naturally exist, and as the small quantity needed for canals and locks is always available, there is no reason why the diversions for "power purposes" should be interfered with. Every effort should, of course, be made to secure the greatest possible amount of power from the diversions.

75. The small diversion for "power purposes" through the Welland Canal reduces the depth of Lake Erie and, more slightly, of the waters above Lake Erie. It therefore injures navigation on these waters and at the same time detracts from the scenic beauty of Niagara Falls. The diversion existed prior to the promulgation of the present treaty. The physical conditions necessarily render this diversion less economical than a diversion of the same amount taken immediately above Niagara Falls and discharged at or near Lewiston. No increase should therefore be made in the power diversion of the Welland Canal. The injurious effect upon lake levels of this diversion for "power purposes," as well as the smaller one for "navigation purposes" is included in the total damage to be rectified by the regulating dam at the head of the Niagara River referred to above. The injury done to scenic beauty by this diversion and by that at Chicago are included in the measures for the "preservation of scenic beauty" hereafter discussed.

76. On the Niagara River above the Falls there are six diversions "for power purposes," three in each country, and there are two very small diversions for canal navigation on the New York side. The latter two are insignificant and, moreover, the very slight damage they do to scenic beauty and to the depths at points upstream is readily remedied. Then, too, as already stated, such diversions are recognized to be indispensable and their benefits are very general. The six diversions "for power purposes" are sanctioned by the existing treaty, but in 1909, when the treaty was negotiated, it was known that they were undoubtedly detrimental to the "preservation of scenic beauty," certainly of the Falls, if not of the rapids. Yet at that time, no steps were taken to remedy the harm already experienced which had, by an elaborate investigation conducted by the United States Lake Survey, been shown to consist chiefly in accentuating the denudation of the two ends of the Horseshoe, already laid partly bare by the recession of this fall. It was also shown that certain portions of the diversions "for power purposes" from the Chippawa-Grass Island pool produced an adverse effect upon Lake Erie, which, while considerably less than the lowering due to an equal diversion direct from Lake Erie was still of sufficient magnitude to warrant serious attention. The report then made by the Lake Survey suggested possible remedies which later researches prove to be desirable. While we rate the "preservation of scenic beauty" as taking precedence over diversions "for power purposes" we believe that the development of water power is of urgent importance and that such diversions should be not only permitted but encouraged to the extent that it is possible to arrange to make them consistent with proper regard for navigation and without danger to the "preservation of Niagara Falls and the rapids of the Niagara River." We are

hereafter expressing ourselves as believing that works are practicable which would not only neutralize the damage of both kinds that diversions "for power purposes" may justly be charged with, but also would reduce, if not completely prevent, the destructive erosion and recession of the Horseshoe which, more than anything else, have injured scenic beauty. The increase of low-water discharges, to be rendered possible by the regulating dam at the head of the river, would also ameliorate the rapids and the Horseshoe Falls and even before construction of the remedial works permit 20,000 cubic feet per second additional to be diverted above the Falls in the United States and 4,000 cubic feet per second in Canada "for power purposes," leaving all scenic beauty somewhat better than it now is. In addition, a diversion "for power purposes" of 30,000 cubic feet per second in the Lower Gorge is recommended as desirable and really harmless to scenic beauty. We are recommending that the diversion of 20,000 cubic feet per second be conditional upon the completion of an agreement with Canada for the construction of the regulating dam and the appropriation by both countries of the amounts required for its construction, and also that the diversion be used in the development of power under the full head of 310 to 320 feet due to the difference between the levels of the Chippawa-Grass Island pool and the Niagara River just above Lewiston. The diversion of 30,000 cubic feet per second from the Lower Gorge will be the lower stage, with head of some 90 feet, the two more efficient power stations at Niagara Falls belonging respectively to the Ontario and the Niagara Falls power companies. These stations are now in operation and develop power from a total diversion of between 25,000 and 30,000 cubic feet per second under a head of between 200 and 220 feet, that of the upper stage, i. e., difference in level between the Chippawa-Grass Island pool and the Maid-of-the-Mist pool.

77. We now approach the last and probably the most discussed subject on the part of Congress and of the general public, namely, "the preservation of the scenic beauty of Niagara Falls and the rapids of the Niagara River." We have already mentioned the damage to the beauty of the Horseshoe caused by the deterioration of the ends of the crest. This is amply shown by the admirable photographs accompanying the text, in which high discharges covering these usually bare ends are contrasted with the lower flows that expose the unsightly black rock. The denudation of the ends is plainly due to the concentration of flow in the notch which has formed in late years and has spoiled the symmetry of the Horseshoe. This concentration has set up erosion and recession which, in turn, have tended to increase concentration in the notch and accelerated baring of the ends—the familiar vicious cycle. Mist and spray are also the results of this pernicious concentration and they obscure the Horseshoe and render it inferior as a spectacle to the American Fall, which, with far less depth on its crest and much smaller but nearly uniformly distributed flow, is generally regarded as supremely beautiful. The way to insure the "preservation of the scenic beauty of Niagara Falls" is therefore to secure a uniform distribution of the flow and to reduce it to the point where mist and spray will be a minimum. Uniform distribution calls for cutting down the now bare ends and forcing water away from the notch, reduction in volume can be effected only by increasing diversions. To

secure uniformity of distribution, we are recommending the step by step construction within coffer dams of a rough stone or concrete weir whose design and location will be based on model experiments, and the necessary cutting down of the ends and other excavations are to be similarly determined and made. We recommend also that discharge over the Horseshoe be such as will produce from 3 to 3½ feet depth on the reformed crest, a volume that we estimate at about 70,000 cubic feet per second, and that the flow over the American Fall be held at 10,000 cubic feet per second, leaving eventually 100,000 to 110,000 cubic feet per second available for power. The scenic beauty of the rapids both above and below the falls will not only be preserved but improved by the additional diversions.

78. As to Lake Ontario and the St. Lawrence, the desires of Congress are only indicated in a general way as being included in the "entire subject of water diversion from the Great Lakes." Since the passage of the resolution, Congress has directed an investigation of practically the same character to be made by the International Joint Commission. The division engineer gives information as to all existing diversions from Lake Ontario and the St. Lawrence "for navigation, sanitary, and power purposes." He shows that there are none for navigation or power from Lake Ontario and that those for "sanitary purposes" are, as usual, unimportant. While there are diversions for all three purposes from the St. Lawrence, except that at Massena, which, while considerable, is largely compensated, they are all small and their effects of no real consequence. The international portion of the river lies between Lake Ontario and St. Regis. Below St. Regis, it is wholly Canadian. Above St. Regis, there are no interests demanding serious consideration except navigation and power. The volume of this navigation, though only about 5 per cent of that of the upper lakes, is substantial, but it seems unlikely that its importance will ever greatly exceed the possibilities of power development which are enormous. The navigation of Lake Ontario is practically the same as that of the Welland Canal and the St. Lawrence. A regulating dam at the foot of Lake Ontario would obviously help navigation, both on the lake and on the river below it and by equalizing the discharge it would greatly improve the power output. Its construction is desirable, especially to supplement the corresponding dam at Buffalo, but as the International Joint Commission is now engaged in making the investigation demanded by Congress, we forego further discussion of this subject.

79. The preceding discussion enables us to present a logical and convincing solution of the problems connected with water diversions from the Great Lakes and the Niagara River, including navigation, sanitary and power purposes, and the "preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River." by permitting us to appraise the relative value and importance of the three purposes for which water may be used as compared with "the preservation of scenic beauty." Navigation, whether in artificial canals or in open waters, is of higher value and importance than any other end served by the water of the Great Lakes. The depths of the lakes and their connecting channels which may have been injured by diversions for various purposes should be restored and if possible increased, and whatever possible done to benefit navigation. Following

navigation in importance comes the "preservation of scenic beauty of Niagara Falls and the rapids of the Niagara River," which, as we have already seen, demands that the flow shall be uniformly distributed, in somewhat reduced volume over the entire crest of the Horseshoe by means which have been generally outlined. The Horseshoe will thereby be both preserved and improved. The rapids are not in any danger and additional diversions will somewhat improve them. Power comes third in order of importance, and should be served only when the needs and possibilities of navigation and of scenic beauty have been filled. Legitimate sanitary uses are so insignificant in their effects as to require no limitation. The diversion at Chicago is a special case of use for a sanitary purpose, and it will therefore be discussed separately. We shall therefore proceed to discuss the above matters in greater detail in the following order: Navigation, preservation of scenic beauty, power, sanitary use at Chicago.

NAVIGATION.

80. The character, extent, and importance of the navigation of the Great Lakes are generally known, and the division engineer gives a large amount of detailed information as to the commodities carried and the vessels that carry them. The traffic consists principally of bulk freight, iron ore, coal, grain, and stone, carried in large vessels of a peculiar type and most of it originates or terminates at the west end of Lake Superior or the east end of Lake Erie. The channels through the lakes naturally afford practically unlimited depth, but the harbors and the connecting channels have had to be deepened by dredging and set the limitations upon the drafts to which vessels may load. The lakes themselves exhibit considerable seasonal and periodic fluctuations of depth, and the lower stages, occurring generally in the spring and fall, reduce to a minimum the depths available in the harbors and connecting channels. Thus between 1860 and 1920 the monthly mean elevations of Lake Superior varied between 600.7 and 604.1 feet, those of Lakes Michigan and Huron between 579 and 583.6 feet, and those of Lake Erie between 570.7 and 574.5 feet. There have, of course, been daily mean stages considerably lower than these average monthly elevations.

81. Transportation on the lakes is extremely well-organized and efficient, and a system has been evolved under which vessels on every trip have timely notice of the minimum depth available along their route and load to the greatest draft thus indicated as permissible. Advantage is taken of every possible inch of depth and the actual cost of transportation is thereby kept very low. It is easy to see that under such a system every inch of depth is of measurable value. The division engineer has figured that the average earnings for each tenth of a foot of draft of the average lake freights is \$44.57 per trip, or \$590,000 per season for the entire fleet, and this is evidently also the loss from a reduction in depth of the same amount for the number of vessels considered.

82. It is an accepted fact that lowering of all the lakes named has resulted from diversions and changes in the discharge capacity of their outflow and connecting rivers—and the amount of lowering and consequent reduction of depth available at critical points being

known, it is a simple matter of multiplication to arrive at the total annual loss. Table 47 shows the total lowering of each lake by all existing diversions at mean stage. Lakes Michigan and Huron are lowered 0.47 foot, Lake Erie 0.76 foot and Lake Ontario and the St. Lawrence River at Lock 25 about 0.62 foot. If the entire bulk freight traffic of the upper Lakes entered Lake Erie the annual loss would be $7.6 \times \$590,000 = \$4,484,000$. Only about 8 per cent of this traffic pertains to Lake Erie and the yearly loss is therefore \$3,946,000. The loss on the 12 per cent pertaining to Lake Michigan is \$333,000, and that on the traffic of the St. Lawrence Canals \$434,000, the total average annual loss based on recent tonnage being therefore \$4,713,000. To this total loss of earnings the diversion of the Chicago Sanitary Canal, an average of 8,800 cubic feet per second in 1917, contributed \$2,866,000 annually, and even the diversions for power in the Chippawa-Grass Island pool, far below the foot of Lake Erie, lower it nearly one-tenth foot and cause a loss of about \$526,000 each year.

83. While diversions therefore cause great losses which should be ended by works to restore the lost depths, load drafts of vessels are affected still more injuriously by the natural oscillations of the lakes which, over a period of years, have had a range of 4.6 feet on Lakes Michigan and Huron and of nearly 4 feet on Lake Erie. During a single season of navigation the difference between monthly mean high and low waters has been as much as 2 feet. The losses due to this cause are therefore nearly three times as great as those due to diversions.

84. As already stated, at least four different plans have been proposed for restoring lake levels and two of these, those of the Deep Waterways Board, and of the Chicago Sanitary District, contemplate regulating Lake Erie and restoring diminished levels by works that would modify the natural oscillations of that lake. The Division Engineer believes that the former plan is objectionable because it would increase the danger of floods due to winds and ice gorges. Such floods cause a certain amount of damage at Buffalo and Fort Erie and other centers of population near by. In addition, the disturbance of the normal outflow of Lake Erie would affect Lake Ontario unfavorably. We had no opportunity to pass upon the plan of the Chicago Sanitary District which apparently is subject only to the latter objection. The plan proposed by the International Waterways Commission in 1913, a compensating submerged weir of peculiar form extending diagonally across the Niagara River from above the mouth of Chippawa Creek to Gill Creek, would raise the Chippawa-Grass Island pool 3 feet, and by backwater elevate Lake Erie about $4\frac{1}{2}$ inches. It would therefore fall far short of restoring the natural levels of the lake and the oscillations of the latter would remain unaffected. The Division Engineer rejects the first and third plans for restoring levels and proposes to restore the levels of Lakes Erie, Huron, and Michigan by the construction of two sets of submerged weirs. One set of five would be at the head of the Niagara River abreast of Squaw Island, cost about \$2,000,000, and raise Lake Erie 1.27 feet, Lake St. Clair about 0.55 foot, and Lakes Huron and Michigan about 0.16 foot, leaving 0.28 foot to be compensated by dredging in Lake St. Clair. The second set of about 11 weirs, spaced about one-third mile apart in the St. Clair River, would cost \$1,500,000

and would raise Lakes Huron and Michigan 0.60 foot more. The levels of these three lakes and the connecting rivers between them would, at a total cost of about \$3,660,000, be not only fully restored, but provision made for the lowering that would be caused by some additional diversion, the margin on Lake Erie being 0.51 feet and on Lakes Huron and Michigan 0.29 foot.

85. These submerged weirs would leave the natural oscillation of Lakes Erie and Huron undisturbed. They would reduce the discharge capacity of the St. Clair and Niagara Rivers to what it was before any diversions or other artificial changes were made and permit the lakes to fluctuate between such levels as would have resulted from purely natural causes, such as changes in precipitation, evaporation, etc. To design the weirs correctly, proper model experiments would be desirable and also prolonged gauge observation. In other respects, the weirs are a sound and workable solution of the problem of improving navigable depths, in some respects preferable at the time they were recommended to any other plan.

86. Since the Division Engineer's report was prepared, there has been a very marked development of public sentiment in favor of the opening of the upper St. Lawrence River to large vessels, and it seems fairly certain that any such plan will include works for regulating the discharge and level of Lake Ontario. One important objection to restoring the levels of Lake Erie and the waters above it by means of an adjustable or regulating dam will, therefore, be removed, and we believe that the objection as to interference with the discharge of floods and ice would be safely met by providing a dam with sluiceways, operated by Stoney gates, extending completely across the river and by enlarging the area of cross section at the dam and below it through the now constructed section of the upper Niagara River so as to permit the safe discharge of about 400,000 cubic feet per second. On December 9, 1917, the stage of Lake Erie was 579 and the discharge 366,000 cubic feet per second, and on December 7, 1909, the lake reached an elevation of 580.28, corresponding to a discharge of 400,000 cubic feet per second, so that the discharge capacity proposed corresponds to actual conditions.

87. Such a regulating dam at the foot of Lake Erie would have a number of important advantages over the plan of the Division Engineer. It would hold Lake Erie during the season of navigation at a more nearly uniform level, probably between elevations 573 and 574, thereby increasing the low water depths on that lake by perhaps $1\frac{1}{2}$ feet or more, and its range of oscillation during the open season might be reduced to a foot or less. The low-water depths of Lakes Michigan and Huron and of the channels connecting them with Lake Erie would also be improved, the Lakes being raised perhaps 0.2 foot or more and the connecting channels greater amounts. Apparently, depths on Lake St. Clair would be fully compensated for all existing or probable future diversions, and below Lake St. Clair during the season of navigation they would be considerably greater than the undisturbed natural depths would have been.

88. By proper manipulation of the sluice gates of this dam the discharge of Lake Erie might be made very nearly constant, say, from 180,000 to 200,000 cubic feet per second. This would, in turn, greatly benefit the scenic beauty of the Falls, which, when Lake Erie is extremely low with, for example, such an elevation as that of Feb-

ruary 1, 1915, namely, 567.38, and a corresponding discharge of 106,000 cubic feet per second, are materially less beautiful than when the stages and discharges are higher. The discharge at normal low water is considerably greater than the figure just given, being about 160,000 cubic feet per second. Regulation would increase this discharge about 40,000 cubic feet per second, only half the amount added at extreme low stage. This increase, however, would be a real benefit to scenic beauty and it also would permit power diversions to be increased. Furthermore, the regulating dam would enable the remedial works above the Horseshoe to be more safely and readily constructed, as will hereafter be shown.

89. Because of these great and positive benefits, we recommend the construction of the above regulating dam at the foot of Lake Erie close to the site selected by the deep waterways board. No detailed plan has been made for this dam. It is an international matter and should be clearly defined in an appropriate agreement with Canada. We have, however, made a tentative analysis and estimate which show that the plan of control is feasible and that it would not cost more than \$8,000,000. This cost should be defrayed by Canada and the United States upon such a basis as might be agreed to.

90. The regulating dam would not completely compensate for existing losses of depth in the St. Clair River and in Lakes Huron and Michigan and it would not, of course, permit any increases in the diversions that affect those depths. Furthermore, the oscillations of these two lakes and consequently of the St. Clair River would be practically unaffected in range. It is seemingly out of the question to control the oscillations of the Detroit River and of the channels and lakes above it, and, subject to adequate model experiments as to the submerged weirs, we therefore recommend the dredging in Lake St. Clair and the compensating weirs in the St. Clair River proposed by the division engineer for raising the levels and increasing depths, all at an additional cost of \$2,160,000.

91. This regulating dam and the dredging and submerged weirs give practical assurance of the operation of the present type of large vessels with a minimum of inconvenience and uncertainty, and their installation would represent full and liberal provision for the preponderating interest of navigation. They should be begun and completed at the earliest possible moment.

PRESERVATION OF SCENIC BEAUTY.

92. We are now at liberty to pass to the subject next in order of importance, namely, the "preservation of the scenic beauty of Niagara Falls and the rapids of the Niagara River." The report of the division engineer is full and clear in its analysis of what constitutes and causes the scenic effects of the Niagara River and without further discussion we accept his conclusions which are that the chief beauty of the Falls arises from unbroken crest lines, generously supplied with water and clearly visible from advantageous viewpoints; that the American Fall is more beautiful than the Horseshoe because the absence of mist and spray permit it to create a more pleasing impression on the spectator; that the

effect of the Horseshoe is marred not only by the mist and spray but also by the denudation of its two ends; that these are caused almost exclusively by the erosion and recession of the notch with consequent concentration of flow there to the detriment of the remainder of the Horseshoe; that diversions hitherto made for various purposes have slightly injured the Horseshoe; that to reduce its rate of recession the discharge at the notch of the Horseshoe must be reduced by distributing the flow uniformly over the crest line; that some additional diversion for power above the Falls is not only permissible but desirable, because of its effect in reducing erosion and recession; that on the whole all the rapids look best at low stages; and that the beauty of the gorge is largely due to its wooded high banks.

93. So far as concerns the preservation of scenic beauty, the most important measure suggested by the Division Engineer is the construction of a weir and certain rock excavation for the uniform distribution of flow over the Horseshoe, and he believes that this work should be planned only after the river bed above the Horseshoe has been laid bare, its exact formation ascertained and a correct model made to scale and tested. To preserve the flow of the American Fall he recommends a rough submerged weir between the head of Goat Island and the Canadian side, part of which has already been made by dumping dredge spoil.

94. We are in accord with these recommendations of the Division Engineer as to the advantage of distributing as nearly uniformly as possible the water flowing over the Horseshoe Fall and as to the general method by which this can be accomplished. The work to be done consists of the construction of cofferdams so planned as to permit successive parts of the river bed to be unwatered and surveyed minutely, leaving always sufficient channel way unobstructed to provide for the discharge of the river. The construction of these cofferdams is dangerous and difficult, and it should be undertaken only by those who have had practical experience under similar conditions and therefore understand how to cope with the swift current and large discharge. Similar work has, however, been done at this very locality and we have no doubt that the cofferdams can be built, that an accurate model can be made from which, under varying conditions of flow, may be determined the form of the rough structure for diverting most of the flow from the notch and the nature and extent of the excavations necessary in conjunction with it to insure uniform distribution of the flow over the crest of the Horseshoe. The smaller the discharge over the Horseshoe the more easily all this work can be done. By completing the regulating dam at the head of the Niagara River before work is begun on these remedial works at Niagara Falls, it would be possible to reduce the discharge of the river practically at will, and thereby greatly to facilitate the construction of these works. We therefore recommend that no attempt be made to start the remedial works until the regulating dam has been completed and is in operation. The submerged weir for preserving the flow of the American Fall is necessary, and it should be built whenever rock is made available, possibly as a result of the remedial work above the Horseshoe. These remedial works are also international in their scope and therefore call for appropriate diplomatic agreement as to their construction and payment.

maximum of 80,000 horsepower. Due to improvements undertaken during the war, an output of 60,000 horsepower is now produced with a consumption of only 17,000 cubic feet per second. At Waddington, N. Y., a dam 950 feet long was constructed more than 100 years ago across the American channel. The flow through the American channel, known as Little River, is estimated to be 3,000 to 4,000 cubic feet per second, of which about 600 cubic feet is used intermittently and inefficiently in the development of power. A small powerhouse is located at the downstream side of the dam, and a power canal 15 to 20 feet wide leads from the south end of the dam downstream along the bank of the river for about 950 feet, serving four plants. The company owning the rights at this locality has proposed the construction of a new plant to develop 30,000 horsepower, with the use of about 30,000 cubic feet per second.

65. The problem of how the development of power may best be combined with the improvement of the St. Lawrence for navigation is, as stated by the division engineer, at present under consideration by the International Joint Commission. It is not, therefore, advisable to discuss further such plans as have hitherto been proposed for diverting water from the St. Lawrence.

66. Finally, the division engineer discusses the existing boundary waters treaty with Canada, and recommends that it be amended so as to cover the existing needs and anticipate future requirements more satisfactorily and with more flexibility.

67. The recommendations of the division engineer regarding modifications of the treaty and the use of diversions are as follows:

Recommended treaty provisions.—It is recommended that the treaty with Great Britain proclaimed May 13, 1910, be modified in the following particulars:

(1) That the wording of the treaty be altered to extend the jurisdiction of the International Joint Commission to include diversions from tributaries of boundary waters except in the case of diversions from a tributary which are returned to the same tributary.

(2) That the words, "the scenic beauty of the Falls and Rapids," be inserted in the first sentence of Article V after the word "Erie."

(3) That the diversion of water from Niagara River below the Falls be specifically limited in the same manner as the diversion from the Niagara River above the Falls.

(4) That the treaty provide for the construction and maintenance of remedial works of the nature outlined in section (e) of this report; such works to be built under the supervision of the International Joint Commission, or of some other international body created for the purpose; the remedial works to be so designed and constructed that the scenic beauty of the Falls will be restored and preserved when 80,000 cubic feet of water per second is diverted from the Niagara River above the Falls; the expense of constructing and maintaining said works to be borne equally by the high contracting parties.

(5) That the limits of diversion from the Niagara River above the Falls, which the high contracting parties may permit within their respective jurisdictions, be raised from 20,000 cubic feet of water per second on the United States side to 40,000 cubic feet of water per second and from 38,000 cubic feet of water per second on the Canadian side to 40,000 cubic feet of water per second.

(6) That 20,000 cubic feet per second of the water so diverted upon each side of the river shall be returned to the Niagara River at some point or points upstream from turning point No. 134 of the international boundary line adopted August 15, 1913, by the International Waterways Commission under Article IV of the treaty between the United States of America and the United Kingdom of Great Britain and Ireland signed April 11, 1908; and that if any part of the remaining diversion be returned to the Niagara River at any point an equal or smaller amount may be again diverted from any point farther downstream.

(7) That the limits given above be stipulated to apply to the amount actually diverted at any instant, and that accordingly the words "in the aggregate" and "daily" be stricken out of Article V of the present treaty wherever they occur; that it be recognized that small, brief, accidental violations of the provisions of a diversion permit must be allowed if the holder of the permit is to obtain the full value thereof, and that therefore such violations shall be permitted under such regulations as the International Joint Commission shall provide.

(8) That five years after the completion of the remedial works the International Joint Commission, or some other body constituted for the purpose, shall inform the high contracting parties whether or not, in its opinion, further diversions of water from the Niagara River for power development can be made, either continuously or intermittently, without serious injury to the scenic beauty of the Falls and Rapids, the integrity of the river as a boundary stream, or appreciable lowering of lake levels. That, if this opinion be favorable to the further diversion of water, the commission or body shall indicate the amount of further diversion which may properly be allowed, and the conditions by which permits should be limited.

Recommended use of diversions.—In regard to the use of the various diversions of water from the Great Lakes and Niagara River, the following recommendations are made:

(1) That no change be made in the method of dealing with diversions whose primary use is for navigation purposes.

(2) That Federal control of the diversion at Chicago and in the vicinity be established by such measures as are necessary, provided the United States Courts do not uphold the present apparent right of the Federal Government to regulate the diversions there; the Sanitary District of Chicago being permitted to divert from Lake Michigan and its tributaries a total quantity of water not exceeding at any time a flow of 10,000 cubic feet per second; under the conditions that the Secretary of War shall supervise the diversions as he deems best, that the expense of supervision shall be paid for promptly at stated intervals by the Sanitary District of Chicago, that no dangerous conditions shall be created in navigable waters, that the sanitary district agrees to be responsible for any damage claims arising because of the diversion, that it shall pay its share as determined by the Secretary of War of the cost of such compensating works as the Federal Government considers necessary because of diversions of water from the Great Lakes system, that it agrees not to request or make any diversion in excess of that herein stated, that it shall pay to the United States for water used for power purposes at a rate per cubic foot to be based upon the relative value of the power as developed and that which could have been developed by its use at Niagara Falls, N. Y., and along the St. Lawrence River, and that it does all in its power to secure any State authority needed to enable it to undertake the establishment of provisions for sewage disposal other than by dilution and when so enabled provides as rapidly as necessary such sewage disposal facilities as are needed to care for the growth of the district.

(3) That consideration be withheld on all proposals for water diversions for combined navigation, power, and sanitary purposes unless of far-reaching importance and effects and consistent with plans approved by the International Joint Commission as remedial against the pollution of boundary waters.

(4) That the present method of controlling the power diversions at Sault Ste. Marie be not disturbed.

(5) That the total diversion through the Welland Canal for power development be limited strictly to the present amount.

(6) That the diversion through the New York State Barge Canal for power development be limited to the 500 cubic feet per second now allowed.

(7) That as soon as a treaty has been negotiated with Great Britain along the lines indicated in section (k), additional permit or permits be granted so as to make the permitted diversion from Niagara River above the Falls on the United States side 40,000 cubic feet per second, one-half of which is returned to the river in the Maid-of-the-Mist Pool.

(8) That the Secretary of War, the International Joint Commission, or a special board of engineers be requested to prepare plans and estimates in detail for a comprehensive system of compensating works for restoring the levels of all the lakes and their outflow rivers, these plans to be submitted to the International Joint Commission for approval, with the intent that such works be constructed and paid for jointly by the United States and Canada.

minished without grave danger. While as the result of regulation under our proposals a discharge of that volume would be provided in the entire river channel below the Falls, we believe that ice conditions in that portion of the river merit some discussion. The mere accumulation of ice anywhere is, of course, unobjectionable, unless it does damage. Below the Falls there are only two localities where ice gorges form, namely, above the cantilever bridge with occasional damming and super-elevation of the Maid-of-the-Mist pool, and at the mouth of the river, where gorges have also been known to raise the river level from Lake Ontario practically to the Lower Rapids. During the exceptionally severe winter of 1908, gorges occurred at both these localities. The upper one raised the water level sufficiently to flood the power house of the Ontario Power Co. Since that time the company has closed the openings through which the water then came so that a similar interruption of its service and damage to its generators could not occur. The stations of the Hydraulic Power Co. were, however, not harmed, and the only other injury was some disturbance of the tracks of the Gorge Railway. With proper use of the flushing capacity of the Lake Erie regulating works, in conjunction with the minimum discharge of about 90,000 cubic feet per second that we hereafter recommend, ice gorges in the Maid-of-the-Mist pool and lower river should become rare, if not impossible, and with proper interconnection of the power plants in the Niagara district and efficient arrangements for cutting off nonessential use and reducing essential use to a minimum during such emergencies as arise as the result of ice damage, we feel confident that loss to the public, while improbable, would, in any event, be small. In short, ice gorges in the lower river, never frequent, would become far less so, and their evil effects, always comparatively unimportant, would largely be neutralized.

101. The regulating dam at the head of the Niagara River will afford a nearly constant flow of from 180,000 to 200,000 cubic feet per second. If a constant discharge of from 70,000 to 80,000 cubic feet per second would, as we believe, create the greatest attainable scenic beauty at the falls and amply take care of ice above them, there would be available for diversion about 100,000 cubic feet per second. At present, the diversions on the New York side are an average of 1,600 cubic feet per second through the New York State barge canal, and 19,500 cubic feet per second, taken near Port Day into the canals of the Niagara Falls Power Co., the total diversion in New York being, therefore, about 21,100 cubic feet per second. On the Canadian side, the total diversion by the three power companies at Niagara Falls is about 33,000 cubic feet per second, and the entire diversion from above the falls may be put at 54,100. All the power diversions, except that at Lockport, N. Y., discharge into the Maid-of-the-Mist pool, which is 220 feet below the Chippawa-Grass Island pool. The small diversion at Lockport is evidently quite inefficient. Of the five distinct power developments at Niagara Falls, only two are utilizing efficiently anything like the full head of 220 feet, the Ontario Power Co. taking about 13,000 cubic feet per second on the Canadian side and station No. 3 and its extension belonging to the Niagara Falls Power Co. diverting about 12,000 cubic feet per second on the New York side. The others use in the neighborhood of only 140 feet head.

102. While the safe limit of diversion from above the falls would be about 100,000 cubic feet per second after the completion of the regulating dam at Buffalo, we see that for power purposes this represents an increase of but 45,900 cubic feet per second, or only 42,900 cubic feet per second, if Canada be assumed to take the full 36,000 cubic feet per second now permitted under the treaty. We are sure that no sound reason any longer exists for the unequal division of the total diversion. Accordingly, Canada should ultimately receive 13,450 cubic feet per second of additional water for power purposes and the United States 29,450, thereby making the diversion of each country eventually 49,450 cubic feet per second. In the beginning, however, we think it wise to limit the increases to 20,000 cubic feet per second on the American side and to 4,000 cubic feet per second on the Canadian, postponing further diversions until a sufficient opportunity has been had to observe the effects of the regulating and remedial works. As will be explained hereafter, not even the initial increases should be made until the construction of the regulating dam, upon whose operation the increases clearly depend, has been agreed to, funds provided, plans completed and contracts let.

103. We now come to the subject of diversions from the Maid-of-the-Mist pool and lower gorge. We have already stated that the division engineer assigns a present limit of 40,000 cubic feet per second to such diversions. He, however, believes that experience and close observation may justify a higher figure. This limitation is based upon his belief that a minimum flow of about 90,000 cubic feet per second is needed below the falls to take care of ice. Accepting this volume of 90,000 cubic feet per second as approximately the correct minimum, it is readily seen that the equalizing of the flow of Lake Erie at 180,000 to 200,000 cubic feet per second introduces a condition with which the division engineer did not reckon as does also our provision of 70,000 to 80,000 cubic feet per second as the minimum flow over the falls.

104. As already stated, two of the existing power stations at Niagara Falls are efficient. Because of the relatively short distance between their intakes in the Chippawa-Grass Island pool and their outlets at the head of the Maid-of-the-Mist pool, a mile or less, these plants were economical to construct. Built many years before the outbreak of the World War, it is probable that their construction cost per horse-power at the switchboard was less than the cheapest plan of developing the entire head would now afford. It is therefore unlikely that these two plants will ever be abandoned. As they discharge about 25,000 cubic feet per second into the Maid-of-the-Mist pool, after the plans recommended by us have been completed, the discharge immediately below the falls will be 115,000 cubic feet per second. Furthermore, the Niagara Falls Power Co. is understood to claim the legal right to use at least 3,100 cubic feet per second, and possibly 7,500 cubic feet per second in addition to the quantity now used efficiently by its station No. 3, and to be planning to develop power from this added flow. Ultimately, therefore, over 30,000 cubic feet per second may be diverted around the falls and developed efficiently under the head of 220 pertaining to the upper stage, and then the total minimum flow of the Maid-of-the-Mist pool will be about 120,000 cubic feet per second. As 90,000 cubic feet per second is necessary for scenic effect as well as for ice discharge, we

recommend that not exceeding 30,000 cubic feet per second be permitted to be diverted farther down in the Maid-of-the-Mist pool for the development of the second stage of about 90 feet, producing roundly 240,000 horsepower. Such a diversion is now permissible under the treaty, and we recommend that it be made at the earliest possible moment, for the demand for power is urgent, and the development can be made without injury to the scenic beauty of the lower gorge. Construction should probably be under a pressure tunnel plan, and would require not less than two years.

105. Certain other aspects of this first step in our power program are of interest. The best plan for this development is one that would allow the greatest latitude in the choice of licensee, and thereby permit a selection most favorable to the public interest. The ice and other difficulties which led the division engineer to prefer the "compound two-stage" plan are not, in our opinion, sufficient to justify the selection of a plan that limits freedom of choice of licensee, and involves the construction of an extra 5,000 feet of tunnel, costing at least \$3,700,000 more than would be necessary were the intake placed in the gorge at an appropriate point above the railroad bridges. The division engineer has estimated the cost of the second stage of his "compound two-stage" plan as \$209 horsepower for a diversion of 20,000 cubic feet per second producing 164,000 horsepower. Omitting the cost of 5,000 feet of tunnel and of certain other work peculiar to the "compound two-stage" plan, the cost per horsepower becomes about \$185. For a diversion of 30,000 cubic feet per second, we are safe in assuming the cost to be about \$150 per horsepower. This saving on cost and the other advantage mentioned above justify us in recommending that this diversion from the lower gorge be completely independent of the upper stage.

106. Certain objections arise in connection with this diversion, but they can be met. Because of the much longer tunnels needed in Canada, it is evident that a similar development there could be made only at prohibitive cost. This, added to the fact that in diverting 30,000 cubic feet per second, we are taking all that should at present be taken out of the Maid-of-the-Mist pool direct, might cause the feeling in Canada that we are getting more than our fair share of all the power. The point is perhaps not very important, but it might be met by offering, as an equivalent, the cancellation of the existing contract for 50,000 horsepower, more or less, between the Ontario Power Co., and the Niagara, Lockport & Ontario Power Co., to be available for use in Canada as soon as this new water power came into operation in the United States. To enable this block of power to be released to Canada would require, of course, that suitable arrangements be made with the Niagara, Lockport & Ontario Power Co., but it is assumed that this should not present insuperable obstacles.

107. Another difficulty is financial. This new development will carry a construction cost of \$150 per horsepower at the switchboard, whereas a new single-stage development would probably cost from \$80 to \$90, and the existing plants have probably cost less than these latter figures. In a normal market the most expensive plant might be unable to compete with the others, and it might therefore be hard to finance, but as conditions now are it should be comparatively easy to overcome this difficulty and thereby to attract capital for

this development. Even with an assured construction cost of \$150 per horsepower, it should be possible to deliver this power to the consumers at \$30 less than the rate now charged by efficient central steam stations, and yet to earn a fair profit on the investment. If we arrange to charge the consumer \$10 more, i. e., to reduce his saving to about \$20 per horsepower, and set aside this \$10 annually as a fund to amortize the excess portion of the construction cost, at the end of four or five years, which is the earliest that a new single-stage plant could come into operation, the accumulated surcharge would, with compound interest, reduce the original capital cost to about that of the single-stage plan. Thereafter this proposed plant and the new single-stage development could compete on equal terms, provided the original franchise for the more expensive plant were made correspondingly longer than that of the single-stage plant.

108. In making this suggestion, we are taking cognizance of the policy laid down in section 10 (*d*) and (*g*) of the "Act to create a Federal power commission, etc.," having in mind that in this case the franchise would be of unusual value due to the constant dependable flow and to proximity to a market having a large unsatisfied demand for power and every prospect of continued growth.

109. The danger of ice interruption to a plant in the gorge has been touched on above. Assuming stable and solid construction, the worst that could happen would be that for a greater or less time the supply of water would be cut off and it would therefore be impossible to generate electrical energy. We have already shown that this danger would be minimized, if not entirely eliminated, by the proper use of the regulating dam at Buffalo. Any interruptions would probably be short, and during this time essential needs might be supplied by the use of interconnections of liberal capacity between the power stations on the United States side. It would, of course, be still better if good interconnection could also be arranged with the Canadian power plants. During the World War it became necessary for the Secretary of War to assume charge of all power systems at Niagara Falls and Buffalo and to administer their power for the greatest benefit of the war program. Though nonessential use was reduced and much essential use, not otherwise possible, was supplied with power by this unified control, the results would have been far better had ample interconnections then existed between the four principal systems. Such interconnections should now be planned, and before new diversions are authorized the Federal Power Commission should insure their installation, as well as some adequate arrangement for unified control, during emergencies, of all Niagara power and its allocation under some proper priority program such as that set up by the War Industries Board.

110. We have already stated that, contingent upon prior international agreement to construct the regulating dam at Buffalo, the appropriation of the necessary funds by both nations, the completion of definite and detailed plans, and the actual letting of contracts for the entire work, we recommend the diversion of 20,000 cubic feet per second additional in the United States and 4,000 cubic feet per second additional in Canada. Some statement of our views as to the best manner of utilizing this increase is therefore undoubtedly called for. We agree with the division engineer that the

enlarged Welland Canal will for many years take care of all demands of navigation and, as he has shown that the use of this 20,000 cubic feet per second in a combined power and navigation canal would cost \$20,000,000 more than a separate ship canal of suitable dimensions and a power canal for the above volume of water, we concur in his view that the construction of a combined power and ship canal is inadvisable. We also are of the opinion that any new diversion of 20,000 cubic feet per second in the United States should develop the full head of 310 feet or more.

111. The division engineer estimates that for an assumed diversion of 20,000 cubic feet per second developing the entire head of 310 feet or more, the construction cost of a power canal would be \$12.70 per horsepower less than that of a pressure tunnel development and \$15.70 per horsepower less than that of a tailrace tunnel plan. He, however, draws attention to the omission of certain items affecting the ultimate cost of the canal, such as damages to real estate, interruptions of highways and railroads, as well as the difficulties caused to the sewage and water supply systems of a city such as Niagara Falls. All these would add greatly to the final cost of a power canal, and we believe that, in the end, its cost would fall little below those of the other two types of development. We therefore feel that, as to cost alone, there is little to choose between them and that choice must be based on other considerations. An open canal 5 miles long is more likely to have operating troubles due to the formation of ice in its channel than either type of tunnel. The conclusive objection to this type of development is that it would restrict the National Government in the award of the license and, as a result, the terms secured for the public might not be as favorable as would result from the adoption of either the pressure or the tailrace-tunnel plan. The tailrace tunnel seems, on the whole, to give the greatest latitude in this regard, and as its power house is nearer the probable center of demand for power, thereby reducing transmission losses and the cost of transmission lines, and as, further, its power house is safer from danger of damage by ice gorges, which, though slight, in the lower gorge may at extremely long intervals prove real, we recommend the adoption of the tailrace-tunnel plan. The suggested difficulty as to surges and vacuum effects in a long tunnel can be solved by providing and retaining as vents a sufficient number of construction shafts.

112. Assuming that the conditions antecedent to starting the single-stage diversion would require a period of from 2 to 3 years for their fulfillment, and that construction work would take 4 years, at the end of about 7 years from the commencement of negotiations there would be available in the United States 240,000 horsepower from the lower stage, 580,000 horsepower from the single stage, and possibly 60,000 to 150,000 horsepower from the upper stage development, a total of 880,000 to 970,000 horsepower, which would save at least 10,000,000 tons of coal each year and possibly \$30,000,000 or more in the cost of power.

113. Under our power and diversion program above outlined, involving the ultimate taking of 80,000 to 100,000 cubic feet per second, the total lowering of the Chippawa-Grass Island pool would be about 2 feet. This would be compensated by the submerged weir proposed to be built from the head of Goat Island to the Canadian

shore. The lowering effect on Lake Erie, about 0.2. foot, would be taken care of by the regulating dam at Buffalo.

DIVERSIONS FOR SANITARY PURPOSES.

114. Diversions for water-supply and sewage purposes have already been discussed and, with the exception of the diversion of the Chicago sanitary district, they have been disposed of. We therefore revert to this important permanent diversion at Chicago. The case is so well known and the information in the report so full as to call for little further discussion of its merits. Granting that disposal by dilution was the most practicable plan at the time of its adoption, the fact remains that the Chicago sanitary district has for practically 20 years been on notice that the United States was unwilling to allow the district to divert more water than the limit set in the permit of 1903, namely, 4,167 cubic feet per second. Notwithstanding this, the district has since then greatly expanded its boundaries and enlarged its plans, and from year to year, in the face of the opposition of the United States, has diverted more and more water, until in 1917 the yearly average diversion was 8,800 cubic feet per second, which is more than twice the lawful amount.

115. The district can no longer fairly plead the absence or the impracticability of other safer methods of handling sewage and of protecting its people from water-borne diseases. Certainly, for the past 20 years, expert opinion has held disposal by dilution to be inferior to other methods of treating sewage, and enlightened public opinion has condemned a policy which, in effect, is the transfer of a nuisance from our own front door to that of our neighbor. Large cities on the Great Lakes cannot safely drink raw lake water, nor should they discharge unscreened and unfiltered sewage either into the lakes or into tributary streams. In 1915, the Chicago Real Estate Board employed three experts, of whom two were of acknowledged eminence in England, and the third a New York expert of well-known authority, to investigate the sewage problem of Chicago and to present their views as to the best way of solving it. Their report entitled "A Report to the Chicago Real Estate Board on the Disposal of the Sewage and the Protection of the Water Supply of Chicago, Illinois," by Messrs. Soper, Watson, and Martin, has been printed, and its conclusions are, therefore, well known to the public in general, and particularly to the people of Chicago whom they advised substantially in accordance with the views above expressed. Chicago is, therefore, debarred from any claim for indulgence as to work done and expenditures incurred in recent years. If, in defiance of the opposition of the Government, and in open disregard of the law, the officials of the Chicago sanitary district have continued to expend the money of their constituents in the prosecution of unwise and illegal plans, these officials and their constituency are to blame, and they should expect no great indulgence from the general public whose government they have ignored and whose interests they have disregarded.

116. Quite recently, at the end of many years of delay, a decision in the suit of the United States to restrain the sanitary district from the diversion of more water than was authorized in its permit

of 1903, has been made public. As was expected, the judge has felt constrained to uphold the authority of the United States, but it is not believed that any injunction has issued against the district. Also, recently, the district, as noticed earlier in this report, has admitted the damage done to navigation by the diversion at Chicago, and is understood to be prepared to install and pay for remedial works, contingent upon the grant by the United States of authority permanently to divert 10,000 cubic feet per second. The views of the division engineer as to this matter are summarized in paragraph 183(2) of his report. We agree with him except that we believe that the diversion should be limited to 6,800 cubic feet per second, and that, as the use of the water for developing power is more or less an incident to its use for dilution, we regard as inadvisable the tax that he proposes, though we concede that such a tax would be equitable. It would, however, be difficult to assess correctly and it might prove onerous. Apparently, the public interest would be sufficiently satisfied were assurance given that all the power derived from this diverted water, a possible 70,000 to 80,000 horsepower, would be conserved and administered for the benefit of the people of Illinois, and therefore not alienated to any individual or corporation operating solely for private profit. His recommendations that the diversion shall be supervised by the United States at the expense of the sanitary district, and that provision be made at the earliest moment for the installation of a method of sewage disposal other than by dilution, are excellent, and we concur in them. We believe, further, that the Chicago water supply should receive such treatment as will render it at all times safe. The diversion above recommended would permit 2,000 cubic feet per second to be taken by way of the Calumet River, 4,800 cubic feet per second by the Chicago River, and allow the operation of all power-generating machinery now installed at Lockport, Ill. It would also afford the statutory dilution of $3\frac{1}{2}$ cubic feet per second per 1,000 of population for a total of 2,100,000 people.

OTHER SUBJECTS.

117. Since the division engineer's report was submitted, the "act to create a Federal power commission, etc.," has been passed by Congress and approved by the President. Its provisions will therefore govern the issue of licenses for existing or future diversions from the Great Lakes for power purposes. Section 7 of this act indicates the will of Congress as to the choice of licensees and requires that preference be given to applications made by States or municipalities. Without attempting to forestall the action of the Federal power commission, the record shows that the city of Buffalo contemplates making application for a license to divert water for power purposes from the Niagara River. In this connection it should be said that the amount of central station electric power now used within the city limits of Buffalo is about 250,000 horsepower, and the growth of the next five years may be somewhat liberally figured at 100,000 horsepower. Beyond that time growth is more or less problematical, but it is fairly certain that a long time would elapse before Buffalo would be able to absorb as much as 300,000 additional horsepower, the amount of energy from a single-stage development of a diversion

of 10,000 cubic feet per second. Such a development would be considerably less economical than one of 20,000 cubic feet per second capacity, and, in the general interest, rather than authorize a small and relatively expensive project for the sole benefit of Buffalo, it would be wiser to satisfy the needs of Buffalo, while, at the same time, permitting development to be made upon an economical scale. A partnership arrangement might not prove out of question, under which private interests could join the city in making a single large new development of, say, 20,000 cubic feet per second.

118. We have hitherto said nothing about the uses to which power hereafter to be developed should be put. This is a matter that probably should be dealt with by others, but, as some discussion of it has taken place, it seems permissible to indicate our belief that the electrochemical industries should by no means be permitted to monopolize any increase to the detriment of the general user. In our opinion, care should be taken to see that small factories and other similar demand from the general public will be supplied, and that reasonable future increase in this kind of load will be cared for. When this has been done, any balance may, under contracts reserving the right to reduce the supply in favor of general needs, be assigned to electrochemical uses. By this policy profitable employment is assured for a much larger population than would be possible were electrochemical use given preference. The electrification of railways should also be given precedence over any large electrochemical demand.

119. We have recommended that 30,000 cubic feet per second be diverted from the lower gorge immediately, and that 24,000 cubic feet per second additional be diverted from above the falls as soon as the existing treaty has been amended and certain conditions as to the regulating dam at Buffalo have been met. Subject to such temporary restrictions as may, during severe winters, prove necessary, we believe that these limits should be regarded as daily averages, and that it would be desirable to take notice of peak loads and load factors, thereby affording the most economical use of all diverted water. To enable this to be done, a unified control and supervision constantly in close touch with all conditions should be installed, and the load factors affecting diversions should be fixed as conditions from time to time indicate.

120. Liberal interconnections between all power stations have been shown to be indispensable, and every license should make elastic provisions for their installation. These interconnections will facilitate the unified control above suggested. Their capacity can be fixed only by a careful survey of the tributary territory and its power demand, and this may well be deferred until these matters come before the Federal power commission.

121. The immediately preceding paragraphs show that, in reality, the division engineer is correct when he states in his paragraphs 179 and 180 that the water power of the Niagara River is a monopoly. In many essentials, it is a monopoly, and our recommendation of unified control contemplates the recognition of its monopolistic character, and the exercise by the United States of such restrictive powers as are thereby made advisable. We, therefore, feel that the objection raised by certain interests to this portion of the division engineer's report is adequately met not only by him, but also by the precautions above suggested by us.

FINAL SUMMARY AND GENERAL RECOMMENDATIONS.

122. We have above stated that in considering the various uses and effects of diversions from the Great Lakes, they should be arranged in the following order of value and importance: Navigation, scenic beauty, and power. We have also reported that diversions for legitimate sanitary purposes consume so little water that there need be no restriction on them, but this statement does not apply to the Chicago diversion. For the benefit of navigation, we have recommended the immediate construction by international agreement of a regulating dam at Buffalo to cost about \$8,000,000. This dam would equalize the discharge of Lake Erie and raise its level more than it has been, or is likely to be, lowered by diversions from the Great Lakes system, and it would also restore the depths of the Detroit River. At such later time as may prove necessary, we recommend dredging in Lake St. Clair, and a system of submerged weirs, at a total cost of \$2,160,000, these requiring also international action and being intended to repair damage done to Lake St. Clair, the St. Clair River, and Lakes Huron and Michigan. For the preservation and betterment of scenic beauty of the Niagara River, we are recommending a submerged distributing weir built in the dry above the Horseshoe, and the removal of portions of its rocky crest and bed. This work also requires international agreement, and it should not be executed until the regulating dam at Buffalo has been put in operation. We also recommend a submerged weir from the head of Goat Island to the Canadian shore. This will protect and increase the discharge of the American Fall, and will also restore the level of the Chippawa-Grass Island pool, which would otherwise be considerably lowered by the power diversions we now recommend. While this submerged dam really helps navigation, we charge its cost and that of the distributing weir to scenic beauty. Their total cost would be \$6,000,000. For the improvement of the power supply, we recommend the immediate diversion and development of 30,000 cubic feet per second from the Maid-of-the-Mist pool. The head is about 90 feet and the power output about 240,000 horsepower, costing about \$150 per horsepower in the bus bar. Contingent on the conclusion of an international agreement and contracts for the regulating dam at Buffalo, we also recommend that additional diversions of 4,000 cubic feet per second in Canada, and 20,000 cubic feet per second in the United States, be authorized, the diversion in the United States to develop about 600,000 horsepower, under the full head available between the Chippawa-Grass Island pool and the lower river near Lewiston, at an estimated cost of \$80 to \$90 per horsepower. We also recommend that this diversion be not divided between several licensees, but that contending interests be taken care of under some form of partnership arrangement. Finally, as to power diversions, we state that the limit may probably eventually be raised to between 100,000 and 110,000 cubic feet per second, the increase being dependent on the measure of success attained in operating the regulating dam at Buffalo. As to the diversion at Chicago, we are recommending that the existing permit for 250,000 cubic feet per minute be replaced by one for 408,000 or 6,800 cubic feet per second, and that the Chicago Sanitary District, and the City of Chicago be required

to provide appropriate treatment for both sewage and drinking water.

123. The public need for better navigation and for a greater supply of water power, and the value of improved navigation, scenic beauty, and enlarged power supply, are so very great that we urge that the promptest action be taken to enable our recommendations to be placed in effect. We especially urge that negotiations be at once undertaken looking toward the amendment of the existing treaty.

124. The division engineer has recommended certain changes in the treaty with Great Britain, proclaimed May 13, 1910. Except as modified in our recommendations already made, we agree with his views. The changes proposed in his (1), (2), and (8) should be made. The change suggested in (3) should be amplified by adding the words "so as to limit it to a daily rate not exceeding 30,000 cubic feet per second, until such time as further observations may indicate that this amount may be exceeded without detriment to the scenic beauty and the ice-discharging capacity of the Niagara River below the Falls." The modification suggested in (4) should be based upon the navigation and power program recommended by us, namely, an immediate agreement as to the regulating dam at Buffalo, prompt arrangements for its definite design, and joint financial provisions for its construction under an appropriate contract. The remedial works above the Horseshoe Falls, and the compensating weirs at the head of Goat Island and in the upper St. Clair River, and the dredging in Lake St. Clair should be covered by the same agreement, but work on them should not begin until after the regulating dam has been completed. No definite limit should be set upon the critical discharge over the Falls and the amount of water permitted to be diverted other than to state that the remedial works should be designed so as to afford the maximum attainable scenic beauty, in our opinion corresponding to an ultimate diversion of 100,000 to 110,000 cubic feet per second.

125. The limits set in (5) accord with our views as to what may be diverted after definite provisions have been made for the construction of the regulating dam at Buffalo, but we believe that it will eventually be found desirable to increase these diversions. Accordingly, (5) should be amended by inserting the words "whenever joint arrangements for the regulating dam at Buffalo have been completed, funds appropriated, and contracts for the construction of the dam entered into," to follow the initial word "That." The words "These diversions may be further increased as provided in (8) hereafter" should be added at the end of (5).

126. The proposal of (6) will also require modification to make it accord with our power plan. This may be effected by substituting the opening words, "That not less than 30,000 cubic feet per second of the water so diverted shall be returned, etc." The remainder of the provision may remain unchanged.

127. We have already recommended suitable provision for making allowance for peak loads and the load factor. The change proposed in (7) is out of harmony with our recommendations and we suggest the following: "(7) That the limits above given be understood to be daily rates of diversion corresponding to the load factors characterizing each individual power station. Whenever ice or other

conditions render restrictions necessary in the public interest, steps may be taken by the high contracting parties, either jointly or severally, to reduce all or any authorized diversions until such time as the emergency is considered to have passed."

128. As to the use of diversions, as recommended by the division engineer and quoted verbatim in paragraph 67 under the caption "Recommended use of diversions," we agree with the division engineer's views as expressed in (1), (3), (4), (5), and (6). We have indicated in the preceding paragraph and in the general discussion the extent to which we differ from (7) and (8), and nothing further as to them seems called for. As to (2), relating to the Chicago sanitary diversion, we believe that the maximum should be 6,800 cubic feet per second, and that the provision for exacting payment is inexpedient. Otherwise, we agree with the division engineer's recommendations as to Chicago.

129. In closing, we desire again to express our opinion that the report is of great and permanent value. We, therefore, recommend that it be printed in its entirety and that all inclosures and illustrations be reproduced, except Appendix I, which has already been printed in connection with hearings held in 1918 before the House Committee on Foreign Affairs.

For the board:

H. TAYLOR,
Brigadier General, United States Army,
Senior Member of the Board.

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REPORT ON INVESTIGATION OF WATER DIVERSION FROM GREAT LAKES AND NIAGARA RIVER.

[By Col. J. G. WARREN, Corps of Engineers, U. S. Army.]

WAR DEPARTMENT,
OFFICE OF THE DIVISION ENGINEER LAKES DIVISION,
Buffalo, N. Y., August 30, 1919.

From: The Division Engineer, Lakes Division.

To: Chief of Engineers, United States Army, Washington, D. C.

Subject: Report on Investigation of water diversion from Great Lakes and Niagara River, N. Y.

There is submitted herewith report on investigation of water diversion from Great Lakes and Niagara River as directed by the Chief of Engineers, United States Army, together with eight appendices which treat of various items of the investigation in greater detail. Appendices A, B, D, E, F, and G, contain the eight sections of a report of W. S. Richmond, assistant engineer, on Investigation of water diversion from Great Lakes and Niagara River. Appendix C is a report of First Lieut. Albert B. Jones, Engineers, United States Army, on preservation of scenic beauty of Niagara Falls and of the rapids of Niagara River. Appendix I is copy of interim report submitted March 2, 1918.

J. G. WARREN,
Colonel, Corps of Engineers, United States Army.

INVESTIGATION OF WATER DIVERSION FROM THE GREAT LAKES AND NIAGARA RIVER.

1. *Introductory.*—The following report covers an investigation into the matter of water diversion from the Great Lakes and Niagara River. The duty of making this investigation and report was assigned to me by letter of the Chief of Engineers dated July 20, 1917 (E. D. 57243), in pursuance of public resolution No. 8, Sixty-fifth Congress, which is as follows:

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That public resolution numbered 45 of the Sixty-fourth Congress, approved January 19, 1917, entitled "Joint resolution authorizing the Secretary of War to issue permits for additional diversion of water from the Niagara River," is continued in full force and effect, and under the same conditions, restrictions, and limitations, until July 1, 1918: *Provided,* That the Secretary of War is hereby authorized and directed to make a comprehensive and thorough investigation, including all necessary surveys and maps, of the entire subject of water diversion from the Great Lakes and the Niagara River, including navigation, sanitary, and power purposes, and the preservation of the scenic beauty of Niagara Falls and the rapids of Niagara River, and to report to Congress thereon at the earliest practicable date. To carry out the provisions of this proviso, there is hereby appropriated, out of any money in the Treasury not otherwise appropriated, the sum of \$25,000.

2. *Progress of the investigation.*—The investigation was gotten under way as promptly as practicable and has been prosecuted with

diligence. A considerable amount of field work required in the vicinity of Niagara Falls was completed in February, 1918. Other field work was of minor importance. The office work which included reductions of field data, the analysis and bringing up to date of the great amount of existing data, preparation of maps, profiles and diagrams, studies of the engineering matters involved, making designs and estimates of proposed works, and preparation of the report, has proved a task far greater than had been anticipated, and the submission of the final report has been consequently delayed. A description of the field and office work is given in Appendix B.

3. *Interim report.*—In compliance with instructions from the Chief of Engineers an interim report was submitted on March 2, 1918. In it certain facts were pointed out and conclusions presented. It is important to note that the subsequent work of the investigation confirms in every important detail the recommendations and conclusions therein contained. This report, together with the action of the department thereon, is printed in Appendix I.¹

4. *Scope of the investigation.*—The general scope of the investigation was indicated approximately in the interim report by an outline of subjects and topics given in the third paragraph. In preparing the final report this outline has been adhered to in general, although minor changes in topics and sequence of subjects have been found advantageous. In the appendices will be found a treatment of each topic and subject in as great detail as is considered essential to a clear and comprehensive exposition, without elaborating historical, technical, or legal details held to be immaterial, and without any attempt to exhaust the subject matter. All diversions of water from the Great Lakes Basin of sufficient magnitude to be considered worthy of mention have been included, whether for navigation, sanitary, or power purposes, the character, quantity, and effect of each being stated. The Niagara diversions are dwelt upon with special emphasis, consideration in detail being given to the subjects of preservation of the scenic beauty of the Falls and rapids of Niagara River and of further development of water power.

5. *Extent of territory involved.*—The territory involved in a comprehensive consideration of these diversions is the entire drainage area or basin of the Great Lakes above St. Regis, N. Y., 66 miles above Montreal, the place at which the St. Lawrence River passes entirely into Canada. This area is approximately 300,000 square miles, of which 59.5 per cent lies on the United States side of the International boundary line. The total area is somewhat larger than that of Texas and about one and one-half times the size of France. The land area on the United States side is greater than the combined area of the New England States and New York State. It includes practically all the State of Michigan and portions of Minnesota, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania, and New York. The land area on the Canadian side comprises a large part of the Province of Ontario. The water surface area alone is 95,205 square miles, and 60,975 square miles of this, or 64 per cent, is in the United States. The main shore line involved exceeds 8,300 miles in length.

6. *Population of the basin.*—The population of the basin area is estimated to be 15,000,000, of whom about 2,000,000 are in Canada.

¹ Omitted; see par. 129, p. 60 of this document. Appendix I was printed in Part 2 of Hearings before the Committee on Foreign Affairs, House of Representatives, 65th Cong., 2d sess., on H. R. 11871, relative to "Diversion of water from Niagara River."

At least 16 cities of over 50,000 population each are located within its boundaries.

7. *Water power of the basin.*—The total developable water power of the basin is estimated at 10,000,000 horsepower, far more than half of which is in the United States. The water power already developed within this area is, roughly, 1,000,000 horsepower in the United States and 1,500,000 horsepower in Canada.

8. *Lake commerce of the basin.*—The lake commerce in 1917 was carried in more than 1,000 vessels of an average registered tonnage exceeding 2,000 tons each, about 90 per cent of the vessels having a registered tonnage of over 100 tons, while 41 vessels had a dead weight tonnage of 13,000 tons or more. The maximum length of freight steamer was 625 feet, maximum beam 64.2 feet, and maximum draft used, 21.9 feet. The total freight passing through Detroit River during the navigation season of 1917 was 95,000,000 tons, valued at approximately one and one-quarter billion dollars. There is a not inconsiderable lake commerce which does not pass through Detroit River. The length of steamer track from Montreal to Duluth is 1,340 miles, and from Montreal to Chicago it is 1,260 miles.

9. *Maps of Great Lakes Basin.*—The drainage area under consideration is depicted on Plate No. 1, on which are shown the outlines of the Great Lakes and connecting and outflow rivers, the outline of the entire basin of the Great Lakes above St. Regis, the outline of the drainage basin of each individual lake, the international boundary line through the lakes, and the general locations of waterways through which water is diverted from the Great Lakes, or tributaries of the Great Lakes, together with other data of a general character. Plate No. 12 is reproduced from Plate 2 of the report of 1897 of the first Deep Waterways Commission, published as House of Representatives Document No. 192, 54th Congress, 2d session.

10. *Diversion of Great Lakes waters.*—In Appendix A is a treatment in some detail of diversions of waters of the Great Lakes Basin, separated into three sections, (a) navigation, (b) sanitation, and (c) power development. Some diversions pertain to only one of these uses, some to two, and others to all three. In Appendix A, where they pertain to two or three uses they are treated under each division concerned, the remarks in each case being confined in so far as practicable to the particular use under consideration, and each diversion is described upon its first mention. For brevity in the following paragraphs the diversions at each locality will be described in turn, all diversions at the locality being considered simultaneously, whether for use of navigation, sanitation, or power development. Attention is directed to the maps and photographs accompanying Appendix A.

11. *Diversions at St. Marys Falls.*—The average volume of flow of St. Marys River is approximately 75,000 cubic feet per second. The drop in water level from Lake Superior to Lake Huron averages 20.7 feet over a period of years, 19.4 feet of this occurring in a rapids three-fourths mile long abreast the city of Sault Ste. Marie, Mich. There is one ship lock on the Canadian side, and there are four on the American side, the fourth lock being under construction and not quite complete. There are three power developments, one on each side of the river involving a power canal, and one in the rapids on the American side. The water diverted is about as set down in Table No. 1.

TABLE NO. 1.—*Diversions at St. Marys Falls.*

[Cubic feet per second.]

Use.	United States.	Canada.	Total.
Navigation.....	800	200	1,000
Power development.....	31,000	12,000	43,000
Total.....	31,800	12,200	44,000

In each case the water diverted is returned to the river in a distance of $2\frac{1}{2}$ miles or less from the point of diversion. It is estimated that the fourth lock will require an average consumption of 350 cubic feet of water per second. These locks require somewhat more water than shown in the table during the open season of navigation and far less during the closed season.

12. The necessary controlling works for maintaining the level of Lake Superior are partly built and partly under construction. They are described in Appendix E. The operation of these works, and supervision of the diversions, are vested in a local board of control established pursuant to recommendation of the International Joint Commission.

13. *Diversion through the Illinois & Michigan Canal.*—The Illinois & Michigan Canal extends from Chicago to La Salle, Ill. For the past few years there has been no direct diversion of Great Lakes waters through this canal, because the connection with Chicago River has been closed up. A small part of the water diverted from Lake Michigan through the Chicago Drainage Canal enters the Illinois & Michigan Canal at Joliet, Ill. This quantity varies from practically nothing at moderate to high stages of the Des Plaines River to nearly 550 cubic feet per second at very low stages of this river. Of this amount only a trifle is used locking boats, an average of about 40 cubic feet per second is used for power development at Ottawa, Ill., and the rest is expended in minor manufacturing uses and in seepage, evaporation, and waste.

14. *Diversion through Chicago Drainage Canal.*—The Chicago Drainage Canal extends from Chicago to Joliet, Ill., connecting the south branch of the Chicago River with the Des Plaines River. The diversion from Lake Michigan through this canal averaged 8,800 cubic feet per second in 1917, daily averages running as high as 10,000. The entire diversion was used for sanitary purposes. As a secondary matter a large portion of this water is used at Lockport, Ill., to develop power under a head averaging 34 feet. The quantity so used in 1917 averaged 6,800 cubic feet per second.

15. It is estimated that 500 cubic feet per second would be ample to serve any navigation requirements of the present canal. Should the Des Plaines and Illinois Rivers be improved to accommodate navigation of 8-foot draft to the Mississippi, a diversion of 1,000 cubic feet per second might be required to meet the needs of navigation only. The present use of the canal for navigation is very small, there having been only 160 lockages at the power house in 1917, the largest boat locked through being 75 feet long.

16. Excavation of the drainage canal was commenced in September, 1892. The Sanitary District of Chicago, a corporation created by the

State of Illinois to carry on this work and provide for the sewerage of Chicago and the surrounding communities, has been in control of operations from the outset. This corporation began dredging in Chicago River in 1896. The canal was first opened for the passage of water on January 17, 1900. The hydroelectric plant at Lockport began producing power in December, 1907. The flow in the canal has mounted fairly steadily from approximately 3,000 cubic feet per second in 1900 to approximately 9,000 in 1917, average annual rate of discharge.

17. The water passing through the drainage canal is in part used again for water power development at Joliet and Marseilles. At Joliet the State has a dam affording a head averaging 10 feet. Here 5,250 cubic feet of water per second are used for power production. A lock of the Illinois and Michigan Canal is located at the westerly end of this dam. At Marseilles a private dam across the Illinois River affords a head of about 11 feet. There is no lock at this dam. A large portion of the entire flow of the Illinois River is used in power development at this point.

18. Improvement of the Illinois River to afford slack water navigation to the drainage canal would result in the production of a total developable head of 116 feet, including the heads now utilized at Lockport, Joliet, and Marseilles.

19. In Section B of appendix A a brief history is given of the great efforts put forth for many years by the city of Chicago to cope with its sewerage and water supply problems. The great and sustained growth of the city has repeatedly frustrated attempts at solution. On several occasions plans were adopted which were expected to cure certain evils, and less than a decade after their completion the growth of the city had rendered the new provisions as inadequate as the old ones had been.

20. The system of sewage disposal now in use was developed because of the city's situation near the crest of a low divide having an immense reservoir on one side just below the crest. This is the lowest point of the divide between the St. Lawrence and Mississippi Basins. While other cities which also draw water supplies from the lakes in front of them, Cleveland and Milwaukee for example, have been forced to install complicated and expensive sewage purification works, Chicago was able to cut through the divide and draw off some of the water of the reservoir, thus forming a stream into which her sewage could be discharged so that it would be diluted, and washed away into the Mississippi Basin. Using pumps at Bridgeport, this method began to be used in a small way in 1848 and was expanded in 1866. In 1887, at the time the present drainage canal was being planned and urged, the matter of adopting some other disposal system was considered seriously and rejected. The art of sewage disposal by any method other than dilution was not then well developed. The fact that such a solution of the city's sanitary difficulties would lower the levels of the Great Lakes and create certain undesirable conditions in the Illinois Valley was recognized, but these disadvantages were minimized by the people whose duty it was to provide adequate sewage disposal facilities. Sufficient data did not then exist to permit accurate prediction of the lowering of lake levels, and the estimates made by those best prepared to make

such predictions indicated lake lowerings only one-third to one-half as great as now known to be caused. Neither the great and sustained future growth of the city nor the vast and important development of lake commerce, which is now 12 times what it was in 1889, were anticipated. There was a disposition, moreover, to go ahead with the project regardless of other interests in the Great Lakes and Mississippi Valleys. The matter of Government interest was considered, but Government sanction does not appear to have been deemed necessary except for change of current in Chicago River.

21. The case of the *United States v. The Sanitary District of Chicago*, now in the United States District Court, Northern District of Illinois, Eastern Division, involves the very important question of Federal or State jurisdiction. This case was placed before the court in bills filed March 23, 1908, and October 6, 1913. The final arguments in this case were presented in 1915. To date the United States Government has been unable in this instance to secure an injunction compelling a State corporation to observe the terms of a permit issued by the Secretary of War pursuant, in the opinion of the department, to his authority over navigable waters prescribed by acts of Congress. Here is a situation in which a single State denies the jurisdiction of the Federal Government over a matter affecting seven other States in the Great Lakes Basin, several States in the Mississippi Valley, and the Dominion of Canada, although the State of Illinois is powerless itself to deal directly with these States or the Dominion, except as, under the Constitution, the other States may sue Illinois in the Supreme Court, and, under the boundary waters treaty, citizens of Canada have the same right of action against Illinois that citizens of Illinois have. The State of Illinois would seem thereby to deny the right of Federal interference should the State of New York, for example, by the construction of sanitary or power development works between Lakes Erie and Ontario lower the water level along the Chicago water front and in the drainage canal. The only remedy would be suit in the United States Supreme Court, which necessarily is often a process requiring years of time.

22. In this connection it may be well to call to mind the fact that the State of Missouri brought suit in the Supreme Court of the United States against the State of Illinois and the Sanitary District of Chicago to prevent the discharge of Chicago sewage into streams furnishing the water supply of St. Louis. This case was dismissed without prejudice after being in court more than six years, on the ground that no material injury to St. Louis had been proved.

23. It seems clear that matters concerning diversions of Great Lakes waters, where such diversions affect more than one State or more than one nation, can be handled adequately only by an executive body of the Federal Government.

24. Whether the method of disposal chosen by the people of Chicago was right or wrong, a condition has been created which deserves most serious consideration and constructive action. The fact must be recognized that the present system has been provided at great expense, most of which is covered by bonds not yet retired, and that an abandonment of this system for an entirely different one would be enormously costly. If the growth of Chicago continues at past rates, the present canal will in a few years become entirely inadequate under the dilution system. It will then be necessary

either to expand the present system and increase the diversion or to undertake the installation of sewage treatment works which will at least provide that the effluent does not exceed in volume the capacity of the present canal. It is time that these matters were decided upon, and plans for the future worked out.

25. *Diversion through Black River Canal.*—The Black River Canal here considered is just north of Port Huron, Mich., and extends from a point on the west shore of Lake Huron, about $1\frac{1}{2}$ miles north of the foot of the lake, westward about one mile to the Black River. From the canal junction the Black River flows $4\frac{1}{2}$ miles southerly through Port Huron to the St. Clair River, about $2\frac{1}{2}$ miles below the foot of Lake Huron. The diversion from Lake Huron averages 400 cubic feet per second. Its use is in flushing out Black River, which otherwise becomes stagnant and very foul and ill smelling. The canal was constructed by the city of Port Huron without Federal permit. Since it conducts water around the rapids at the head of St. Clair River it exerts a lowering influence upon the level of Lake Huron which is important in principle though entirely negligible in amount up to the present time.

26. *Diversion through Welland Canal.*—The Welland Canal is in Canada, $5\frac{1}{2}$ to 19 miles west of the Niagara River. It is $26\frac{1}{2}$ miles long, and extends from Lake Erie at Port Colborne, northward to Lake Ontario at Port Dalhousie. Its total drop from Lake Erie to Lake Ontario averages 326.35 feet. The quantity of water diverted through it from Lake Erie is approximately 4,500 cubic feet per second, and in addition it receives about 40 cubic feet per second from the Grand River, a tributary of Lake Erie. These are average figures, which, of course, are exceeded under conditions of maximum diversions. Of these diversions approximately 900 cubic feet per second on the average the year around are used for navigation, including lockage, leakage, and waste. Of the remainder a very small amount is used for sanitary purposes, and the balance, about 3,400 cubic feet per second, for power development. At DeCew Falls there is a high head hydroelectric plant of good efficiency which has leases for the continuous use of 1,160 cubic feet of water per second, but appears to use about 2,100. The remainder is used inefficiently at a large number of small developments, mostly along the line of the old canal. Diversion from the Grand River began in 1833. Diversion direct from Lake Erie began in 1881. Since that time the diversion has increased, but there has been very little if any increase since May 13, 1910, the date on which the boundary waters treaty was proclaimed.

27. The Welland Canal affords passage between Lakes Erie and Ontario for vessels 255 feet long, 45 feet beam, and 14 feet draft, with ample headroom for tall spars. It is wholly under Canadian control, but is available to both Canadian and United States vessels on equal terms. The only other waterway connecting these lakes is the New York State Barge Canal, which is restricted to 12 feet of depth and $15\frac{1}{2}$ feet of headroom, and affords a connection 204 miles long from Buffalo to Oswego by way of the Erie and Oswego branches. The New Welland Canal, under construction, will afford a waterway for vessels 800 feet long, 80 feet beam, and 25 feet draft. Its operation is estimated to require a diversion of about 2,000 cubic feet per second.

28. *Diversion through Black Rock Canal.*—The Black Rock Canal is at Buffalo, N. Y., where it provides a waterway and modern lock adequate for the largest lake freighters to overcome the swift shallow rapids at the head of Niagara River. The diversion into it from Lake Erie is estimated to be about 700 cubic feet per second, of which 250 leaks back into the Niagara River through the dike, 400 is delivered into the head of the Old Erie Canal, and the remainder is consumed in lockage. Until 1918 the quantity delivered to the Erie Canal at Black Rock was larger, approximating 1,000 cubic feet per second. In the early days of the canal water power was developed at Black Rock, but this practice was discontinued many years ago. The 400 cubic feet per second now discharged into the Erie Canal partially flushes out of the portion of this canal between Buffalo and Tonawanda, now abandoned for navigation purposes, the sewage discharged into it at Buffalo.

29. *Diversion through New York State Barge Canal.*—The New York State Barge Canal system is an improvement of the old Erie, Oswego, Champlain, and Cayuga and Seneca Canals. It extends from Buffalo to Troy, N. Y., with branches to Lake Ontario at Oswego, Lake Champlain, Cayuga Lake, and Seneca Lake. From the Niagara River at Tonawanda, N. Y., it obtains its sole water supply for the western end to a point east of Rochester. The canal system was opened at the western end in midsummer of 1918. To date it is believed the diversion has been somewhat less than the average amount assumed to be required ultimately, namely, 1,237 cubic feet per second. The maximum discharging capacity of the portion of the canal leading from Tonawanda to Lockport varies with the stage of Lake Erie from 1,000 to 3,000 cubic feet per second. East of Lockport the maximum discharge capacity is 1,600 cubic feet per second. As constructed the canal will probably require a diversion of about 1,237 cubic feet per second for navigation purposes. Incidentally a portion of this water may be used for power development at Lockport and to a smaller extent elsewhere along the canal, although this is a secondary use, the same water being required for navigation use also.

30. Until 1918 the Erie Canal diverted water from Lake Erie at Buffalo. This is a diversion of very long standing, dating from 1825.

31. In addition to the diversion for navigation uses there is now being diverted through the New York State Barge Canal from Niagara River approximately 500 cubic feet per second for power development at Lockport and along Eighteen Mile Creek under permits from the Secretary of War and the New York State superintendent of public works.

32. It is an interesting matter, important in principle, though unimportant in effect up to the present time, that the use of the barge canal causes a diversion of about 50 cubic feet of water per second from the Mohawk River watershed into the Great Lakes Basin and a diversion of about 35 cubic feet per second from the eastern headwaters of the Susquehanna River into the Great Lakes Basin.

33. *Present diversions by power companies at Niagara Falls.*—The present diversions of water from Niagara River at Niagara Falls for power development are approximately as given in Table No. 2.

TABLE No. 2.—*Water diversion from Niagara River at Niagara Falls.*

United States:		Cubic feet per second.
Niagara Falls Power Co.—		
Niagara plant	-----	9,450
Hydraulic plant	-----	7,840
Pettebone Cataract Paper Co.	-----	270
Total	-----	17,560
Canada:		
Hydro-Electric Power Commission of Ontario, Ontario Power Co. plant		11,200
Toronto Power Co	-----	12,400
Canadian Niagara Power Co.	-----	9,600
International Railway Co.	-----	125
Total	-----	33,325
Grand total	-----	50,885

34. The Niagara Falls Power Co. has under construction at its hydraulic plant an addition which, when completed, will bring the total diversion by that company up to 19,500 cubic feet per second, with capacity for using at least 2,000 cubic feet per second more. The Hydro-Electric Power Commission of Ontario has under construction an extension of the Ontario Power Co. plant which will increase the diversion of that plant to about 13,300 cubic feet per second. The commission is also constructing a new plant to utilize a diversion of 10,000 cubic feet of water per second under a head of 300 feet. All the other plants enumerated generate power under heads of 214 feet or less, diverting water from the river not more than $1\frac{1}{2}$ miles above the falls and returning it to the river within less than a mile of the foot of the falls. It is to be noted that the new works provide a capacity for diversion on both sides in excess of treaty limits.

35. *Diversions through St. Lawrence River canals.*—The St. Lawrence River canals above St. Regis are four in number, and are all downstream from Prescott, Ontario, which is opposite Ogdensburg, N. Y. In order downstream they are the Galop Canal, overcoming Galop Rapids; Morrisburg Canal, overcoming Rapide Plat; Farran Point Canal, overcoming a small rapids of the same name; and the Cornwall Canal, overcoming the Long Sault Rapids. The diversions are small, and in each case the water diverted is returned to the river again within a distance of 11 miles or less of its point of diversion. The diversion by the Galop Canal is between 500 and 1,000 cubic feet per second, of which, on the average, 200 or less is for navigation use and the remainder for power development. The diversion by the Morrisburg Canal is between 1,000 and 1,500 cubic feet per second, of which possibly 200 is required for navigation use, the remainder being utilized in power development. The Farran Point Canal diverts perhaps 50 cubic feet per second, all for navigation use. The diversion by the Cornwall Canal is about 3,000 cubic feet per second, of which possibly 300 is required for navigation purposes, the balance being used in the development of water power.

36. These canals and their appurtenances have been constructed, maintained, and operated by the Dominion of Canada without any reference to or complaint from the United States, except in the case

of the Gut Dam, which is partly in United States territory; and in case of the North Channel, whose opening it was at one time feared would greatly lower the level of Lake Ontario. These canals were built primarily for the benefit of navigation, and are open for use equally by the vessels of both countries. The development of water power along these canals is a secondary and incidental matter, although much of the water is now diverted solely for that purpose.

37. *Diversion through the Massena Canal.*—The Massena Canal is on the United States side of the St. Lawrence River at the head of the Long Sault Rapids, and extends about 3 miles from the St. Lawrence to a power house on the Grasse River, a tributary of the St. Lawrence. There is a head of about 43 feet at the power house, from which point the last 7 miles of the Grasse River serves as a tailrace, conducting the water back to the St. Lawrence at a point 10½ miles downstream from the point of diversion. The quantity of water diverted is approximately 30,000 cubic feet per second. This development was made under New York State charters, without Federal license or permit, except for minor operations in the St. Lawrence River, first requested after the project had been under construction for several years, and without any reference to Canada until very recently. The development is now controlled through stock ownership by the Aluminum Co. of America.

38. *Water power at Waddington, N. Y.*—At the Rapide Plat the St. Lawrence River is divided into two channels by Ogden Island. The American channel, which is much smaller than the Canadian, is said originally to have had a flow of approximately 26,000 cubic feet per second. A dam was built across this channel at Waddington, N. Y., more than 100 years ago. No Federal permit was sought or granted for this construction, or reference made to Canada. The right to build and maintain the dam was granted by the State of New York in 1808, the purpose being to improve navigation and develop water power. In 1826 the rights conferred were made perpetual, and the ownership of the bed of Little River below the dam was added to the perpetual rights granted. Apparently no question has ever been raised as to the validity of this grant, although a rather similar grant by the State of New York in 1907 to the Long Sault Development Co. of portions of the bed of the St. Lawrence River in New York State was held to be unconstitutional by the State courts, the decision being sustained by the United States Supreme Court. The flow through Little River is estimated to be 3,000 to 4,000 cubic feet per second, of which about 600 cubic feet per second is used intermittently and inefficiently in the development of power. A project is being framed for the proposed development of power at Waddington on a large scale, and certain of the plans have been presented to the International Joint Commission for consideration.

39. *Diversions of cities.*—The only remaining direct diversions of water from the Great Lakes System of sufficient importance to be worthy of mention are the diversions of cities bordering the Great Lakes and outflow rivers for water supply and sewer flushing. The most notable example of flushing is at Milwaukee, where nearly 1,000 cubic feet of water per second is pumped from Lake Michigan to flush sewage from three rivers in that city out into Lake Michigan. At Chicago the pumpage for water supply from Lake Michigan is

1,050 cubic feet per second. At Detroit the average amount pumped from Detroit River is 225 cubic feet per second, while at Buffalo the pumpage for water supply from Lake Erie is 220 cubic feet per second. At Chicago most of the water so pumped ultimately passes down the drainage canal, forming part of the diversion measured at Lockport. At every other city on the Lakes practically all the water so diverted finds its way back within a few miles of the point of diversion, and so produces only a trivial effect upon lake levels.

40. *Diversions from tributaries of the Great Lakes.*—The diversions enumerated in the preceding paragraphs cover all the important direct diversions of water from the Great Lakes and outflow rivers, including the diversion of the Illinois & Michigan Canal which formerly was direct and now is indirect, and the condition at Waddington, N. Y., which is not a diversion, but a closely allied matter. There are several places along streams naturally tributary to the Great Lakes and outflow rivers where diversions or interferences occur which affect the supply of water to the Great Lakes. Prominent among such diversions are: the Grand River in Ontario, a portion of whose discharge has for many years been diverted through the Port Maitland, or Dunnville, feeder into the Welland Canal, and so into Lake Ontario, Tonawanda and Ellicott Creeks; which naturally discharged into Niagara River, diverted into the New York State Barge Canal, and so ultimately into Lake Ontario at Oswego.

41. *Supplies from adjacent watersheds.*—Mention has already been made of the fact that the summit level water supply of the New York State Barge Canal is so arranged that the Oneida and Oswego Rivers, tributaries of Lake Ontario, receive a small amount of water from the Mohawk and Susquehanna watersheds. A similar case is that of the Fox River in Wisconsin, a tributary of Lake Michigan, which receives during high water a small amount of water through the Fox River Canal from Wisconsin River, a tributary of the Mississippi. Formerly the operation of the Ohio and Erie Canal in Ohio caused a small diversion from the Tuscarawas River, a tributary of the Ohio River, into Lake Erie at Cleveland.

42. *Other canals in the basin.*—Other canals which now cause a redistribution of water between adjacent watersheds in the Great Lakes Basin are the Trent Canal, in Ontario, between Lake Ontario and Georgian Bay, and Rideau Canal, in Ontario, between Lake Ontario and the Ottawa River. Abandoned canals which formerly caused such redistribution are the Shenango Canal in Pennsylvania; the Chenango, Chemung, and Genesee Valley Canals in New York; and the Miami and Erie Canal in Ohio. Proposed canals which probably would cause such redistribution are the Lake Erie and Ohio River Canal, the Lake Erie-Lake Michigan Canal, and the Georgian Bay Ship Canal.

43. *Proposed navigation canals, Lake Erie to Lake Ontario.*—Aside from the Welland Canals, and the proposed Erie & Ontario Sanitary Canal, to be mentioned hereafter, the proposed routes of navigation connecting Lakes Erie and Ontario have contemplated using portions of the Niagara River. The first survey for such a canal was made in 1784. Since that date but few years have passed without agitation for the construction of such a canal, and many surveys and estimates have been made. The most recent and also the most elaborate and complete survey and estimate is that of the United States Board of

Engineers on Deep Waterways, whose report, submitted in 1900, was published as House of Representatives Document No. 149, Fifty-sixth Congress, second session. This board surveyed and estimated in detail two routes, known respectively as the Tonawanda-Olcott route and the La Salle-Lewiston route, but recommended the latter as more economical and otherwise preferable. In the course of the present investigation a careful reconnaissance was made of both routes, and revisory surveys of the La Salle-Lewiston route were made in sufficient detail to bring the information up to date.

44. Improvement of the Black Rock Canal, including construction of the new lock at Black Rock, has obviated the necessity of constructing the works designed by the board for the head of Niagara River. The artificial portion of the route extending from La Salle to Lewiston has been redesigned with more liberal dimensions, and an estimate of the cost has been prepared based on present-day prices. In a later portion of the report this canal is considered in relation to its combination with a project for the development of water power.

45. In Section A of Appendix A the matter of a ship canal between Lake Erie and Lake Ontario is treated at considerable length for two reasons: First, to comply with instructions contained in department letters dated August 4, 1916 (E. D. 42608); September 29, 1916 (E. D. 101152); and April 28, 1917 (E. D. 106256), which cover the preliminary examination on "waterway or ship channel along the most practicable route between Lake Erie and Lake Ontario of sufficient capacity to admit the largest vessels now in use on the Great Lakes," ordered by Congress in the river and harbor act of July 27, 1916, which examination and report were originally directed by the department to be included in the investigation reported herein but are now made the subject of a separate report and, second, to comply with department instructions that such a canal should be treated in this report with special reference to the practicability and advisability of making it a combined power and ship canal.

46. For a ship canal without power development the estimated costs are as given in Table No. 3:

TABLE No. 3.—*Estimated cost of ship canal, La Salle-Lewiston route.*

Size of prism.	Size of locks.	Cost.
200 feet wide, 25 feet deep.....	650 feet long, 70 feet wide, 25 feet deep.....	\$120,000,000
200 feet wide, 30 feet deep.....	800 feet long, 80 feet wide, 30 feet deep.....	135,000,000
300 feet wide, 30 feet deep.....	do.....	155,662,000

47. It is important to note that the new Welland Ship Canal, only a few miles distant, which is now partially completed, and which no doubt will be open before a canal in the United States could be constructed, will be able to care for all the traffic likely to exist between Lake Erie and Lake Ontario for many years to come, and that accordingly there is no necessity for an additional canal. Moreover, it should be borne in mind that communication between Lake Ontario and the seaboard is still limited by the St. Lawrence canals and the shallow places in St. Lawrence River. The present commerce through the Welland Canal is only about 5 per cent as large as that

through the Detroit River, and of this small amount not more than 10 per cent is United States commerce.

48. The diversion of water from Niagara River for navigation use in a canal extending from La Salle to Lewiston, would probably be less than 1,000 cubic feet per second.

49. *Proposed canals, Lake Ontario to Hudson River.*—Four water routes from Lake Ontario to the sea have in the past received consideration. These are shown on Plate No. 12. One of them is the natural route by way of the St. Lawrence River. The other three are by way of the Hudson River. Of the routes to the Hudson, one follows the St. Lawrence to Lake St. Louis, an artificial canal from there to the Richelieu River, then up to the Richelieu, through Lake Champlain, and by Woods Creek and Bond Creek to the Hudson; another follows the St. Lawrence to Lake St. Francis, an artificial canal from there to Lake Champlain, and on to the Hudson as before; and the third leaves Lake Ontario at Oswego, following the Oswego and Oneida Rivers to Oneida Lake, across the divide in an artificial canal, and on down the Mohawk River to the Hudson. Only the last route lies entirely in United States territory.

50. The Oswego-Mohawk route was first surveyed for improvement in 1791. In 1829, upon opening the Oswego Canal, this route became navigable, the Erie Canal along the Mohawk River having been opened previously. This route was carefully surveyed by the Board of Engineers on Deep Waterways, and its estimate of cost for a ship canal was presented in the report of 1900. The route was recommended by the board in preference to the route via St. Lawrence River to Lake St. Francis, Lake St. Francis to Lake Champlain via artificial canal, etc., which route was also carefully surveyed by the board, similar estimates being prepared. The building of the New York State Barge Canal along the Oswego-Mohawk route has made the construction of this ship canal as planned impossible, and has rendered very difficult the provision of an adequate water supply for the summit level of any ship canal built along this route.

51. Any diversion of water brought about by the operation of such a canal would amount solely to a redistribution of the water at the summit level between the adjacent watersheds of the Hudson River and the Great Lakes Basin.

52. *Long Sault Rapids project.*—A project to dam the entire St. Lawrence River at the foot of Long Sault Rapids was seriously considered during the years 1907 to 1916. The scheme was primarily one of power development under a head of 40 feet, and secondarily of improvement to navigation under the slack-water system. For this purpose the Long Sault Development Co., a subsidiary of the Aluminum Co. of America, was incorporated in New York State in 1907. In 1913 the State repealed the act of incorporation as unconstitutional, the decision being upheld in the United States Supreme Court in 1916. Congressional authority for the development was sought from 1907 to 1912, but without success. Unsuccessful attempts were also made to secure authority of the Parliament of Canada.

53. *Erie & Ontario Sanitary Canal project.*—The project of the Erie & Ontario Sanitary Canal Co. involves a diversion of 26,000 cubic feet of water per second from Lake Erie, with which it is proposed to develop 800,000 horsepower. About 21,000 cubic feet per

second of this is to pass through the main ship, sanitary, and power canal, which is planned to be 40 miles long, exclusive of the harbors, extending from Seneca Shoal, in Lake Erie, passing south and east of Buffalo and Lackawanna, west of Lockport, and reaching Lake Ontario at Olcott, N. Y. There is to be a ship lock having an 8-foot lift at Lake Erie and two enormous twin lift locks near Lockport, N. Y., one of 209 feet lift and the other of 104 feet lift. A branch canal following the line of the old Erie Canal from Black Rock to Tonawanda, and extending thence easterly to its junction with the main canal, is to be $13\frac{1}{2}$ miles long and carry a discharge of 5,000 cubic feet per second. The depth of the main canal is to be 30 feet and of the branch canal 12 feet.

54. The project of the company is threefold: First to provide a ship canal of ample dimensions connecting Lakes Erie and Ontario, whose control for navigation uses will be turned over to the Federal Government without charge; second, to prevent contamination of the Niagara River with sewage from Buffalo and the Tonawandas and eliminate flood conditions from Buffalo River by providing drainage into the new canal free of charge; and, third, to utilize under a high head for power development all the water permitted by treaty to be diverted from Niagara River for power purposes, thereby earning a revenue sufficient to pay for and maintain the works, and provide a large amount of power in the district. Of the 26,000 cubic feet per second diversion, 6,000 is considered by this company to be a permissible diversion for sanitary purposes. The other 20,000 is to be taken from the present permittees, namely 19,500 from the Niagara Falls Power Co. and 500 from the Hydraulic Race Co. of Lockport, N. Y. These companies are to be compensated for loss of water either by being supplied with an amount of power equal to that now produced, or their properties are to be condemned and purchased.

55. As a navigation project, assuming that provision for such navigation is essential, the proposition is open to two fatal objections: First, the route crosses every railroad and road entering Buffalo from the east, south, and west, some 83 or more altogether, requiring about 70 movable bridges, and the consequent obstruction to traffic would be enormous; second, a better and much cheaper canal can be provided along the La Salle-Lewiston route. There are four other serious objections. The first of these is the lowering of Lake Erie of 1.18 feet at mean stage, which would be caused by this direct diversion. This lowering could be prevented at considerable expense by the construction of remedial works. The second is the production of excessive currents in the Black Rock Ship Canal, and the third is the unduly narrow canal section provided in earth cut. Both these objections could be overcome by canal enlargements, which would be very costly. The fourth is the difficult and dangerous crossing at grade of the New York State Barge Canal. This objection could probably be overcome also at great expense by the use of locks and syphons or by excavation and maintenance of a large basin at the crossing.

56. As regards the sanitary features of the project, they seem both uneconomical and to some extent undesirable. The matter was carefully investigated by the International Joint Commission, which reported that the canal would be highly objectionable and dangerous from a sanitary standpoint if raw sewage were discharged into it,

and that the expense and extent of treatment of sewage from Buffalo and other communities along Niagara River would be greater to prepare the sewage for discharge into the canal than to prepare it for discharge into Niagara River. The report of the commission was adverse and highly unfavorable to the canal. It is generally conceded by sanitarians that water supplies from such streams as the Niagara River must be purified in any event, and money is more wisely expended in purifying intensively the relatively small quantity of water diverted for water supply than in attempting to prevent completely the discharge of impurities into the stream, although nuisances and gross pollution should be prohibited.

57. In regard to the power development features of this project there seems to be no insuperable obstacle to the development of about 787,000 horsepower, an amount slightly less than the stated 800,000, in the summer time. The probability of serious difficulties with ice in wintertime seems very great, because of the enormous quantities of ice which usually pile up in windrows at the eastern end of Lake Erie. The only estimate of cost of the project submitted by the company is based on prewar conditions and prices, and is obviously very much too small. It is \$95,969,000. An estimate comparable to other estimates of power development propositions given in this report has been prepared, the total amount being \$401,760,000. On this basis the cost per horsepower of development would be \$510.50. It is further estimated that the cost of producing power on the bus bars in the power stations would be at least \$65 per horsepower per annum, as against \$10 to \$16 in the new plans proposed to be constructed at Niagara Falls.

58. *Preservation of scenic beauty of Niagara Falls and the rapids of Niagara River.*—The Falls of Niagara, with the rapids and whirlpool in the gorge, constitute what is probably the most famous scenic marvel in the world. Officials of the New York State reservation at Niagara Falls estimate the number of spectators annually at one and one-half million persons, many of whom come from great distances. The total expenditure per annum of these tourists is estimated at \$37,000,000. The destruction or serious defacement of the spectacle or any part of it for power development or commercialization of any kind would, and should beyond doubt, be held almost universally to be intolerable vandalism.

59. *The problem of Niagara Falls.*—There is much to be said, however, in favor of Niagara power and its great benefits to the United States, and to the world. The development already existing made possible the growth in this country of chemical industries so important that it is difficult to see how they could possibly be dispensed with. It might almost be said that the war could not have been won without them. It is true also that the great hydroelectric developments now existing at Niagara Falls furnish a spectacle of beauty, grandeur, and sublimity almost rivaling the Falls and rapids themselves. The problem is to develop a policy which will insure preservation of the natural scenery in so far as justifiable, and at the same time harmonize if possible with present power development and future industrial needs. At first glance it would seem that no harmony was possible, that power development must give way to scenic preservation. A careful study of all the facts makes it clear that this is not the case; that the utmost harmony can readily be made to prevail be-

tween the two apparently conflicting interests, and, strange as it may at first seem, that the scenic preservation may be promoted by a further development of power, with its great enhancement of commercial advantages.

60. *Character of the Horseshoe Falls.*—This very satisfactory condition arises because of the peculiar character and growth of the Horseshoe Falls. While this falls discharges 16 times as much water as the American Falls, and has a crest line 2.6 times as long, yet it is often held to be inferior as a spectacle to the lesser American Falls. It would seem then that for some reason its production represented waste and inefficiency. An analysis of the situation makes the reasons apparent. The crest line forms a deep curve which makes it impossible to see more than about half of the falls at a time, except from one viewpoint in Canada. In the central 1,000 feet of the crest line, situated deep in the curve, more than 80 per cent of the flow over this falls plunges down over the cliff behind a thick cloud of mist. This part of the waterfall is seldom more than partially visible, and then only under favorable conditions of wind which blows the spray to one side. It seems to be a fact that perhaps more than half of the water flowing over this cataract adds nothing at all to the grandeur, unless it be somewhat in the form of noise, while it greatly injures the scenic effect by causing a cloud of spray which hides a large portion of the falls almost perpetually. Meanwhile the ends of the crest line are never well covered with water, and frequently are bare, leaving them very unattractive in appearance.

61. *Erosion of the Horseshoe Falls.*—Not only does the present great concentration of water in the apex of the deep notch in the crest line of Horseshoe Falls represent an absolute loss both to power development and to scenery, but it forms a very destructive agent, eroding the crest line at its point of greatest recession at the rate of 5 feet a year. The recession causes a greater concentration of flow, and the greater concentration, in turn, more rapid and more concentrated recession. It has been remarked aptly that the Horseshoe Falls is "committing suicide." Not only is this a fact, but furthermore, it seems inevitable that if this destructive erosion remains unchecked the crest will, in a very few hundred years, have receded to a point where it will receive the water now flowing to the American Falls, thus utterly destroying this beautiful spectacle, probably the best single feature of all the scenic wonders in the locality.

62. *Horseshoe Falls remedial works.*—The remedy is to construct a submerged dam or weir in the center of the rapids just above the crest of Horseshoe Falls. This would spread the water from the center of the falls toward the ends. Even then it would be advantageous, both to the spectacle and in checking erosion, to divert more water around the falls; and this would be available for generating power. The construction would be unusual and difficult, but it is simple in principle and there appears no reason why it is not practicable, or why it would not be reasonably low in cost. It is believed that the works should not be designed until more thorough surveys have been executed, and extensive experiments made on large models.

63. It is confidently believed that the works as proposed would greatly reduce erosion of the crest line, increase the beauty of the

spectacle, and at the same time permit increased diversion for power production. A submerged weir or dam was first proposed in 1906, and the idea was presented to Congress in 1908 in Senate Document No. 105, Sixty-second Congress, First session, page 15, as follows:—

The dam, if properly planned, would serve to change the direction of the flow, so as to increase the streams that feed the Falls at Terrapin Point and at the Canadian shore. The decrease in the mighty volume that overflows the apex of the Horseshoe would not be noticeable. If built, Canada and the United States should do the actual work under some form of international agreement. A very direct result of the construction of this submerged dam would be a diminution in the rate of recession of the apex of the Horseshoe. This in itself is extremely desirable.

64. *American Falls remedial works.*—It is desirable that the flow over the American Falls be increased slightly, especially if further diversions of water from Niagara River above the Falls are made. The only remedial works required for this purpose consist of loose rock dumped on the bottom of the river above Goat Island and the first cascade. This dump is already partially constructed, and it is believed would be completed by the power companies without expense to the Government, with spoil excavated from such new power development works as may be constructed later.

65. *Present effects of diversions on the Falls and rapids.*—It is indisputable that the present diversions of water from Niagara River for power development purposes have had some detrimental effect on the Falls, and on the depths of water in Niagara River and Lake Erie. This has been demonstrated as a scientific certainty. The only distinctly visible effects, however, are at the ends of the crest of the Horseshoe Falls, and even there they are masked by the effects due to recession of the apex of the crest line, and by changes in stage of Lake Erie. Statements as to the changed appearance of the Falls are sometimes made by persons whose utterances carry weight, either to show that present diversions have greatly injured the scenic beauty of the Falls, or asserting the contrary. The mere fact of these contradictions point to error. As a matter of fact few if any of these observers have taken into account the changes in stage of Lake Erie at Buffalo, largely due to wind, which cause the volume of flow over the Falls to change from hour to hour, day to day, and year to year. Such an observer might well have seen the Falls on two occasions, on one of which the volume of flow due to lake stage was twice what it was on the other occasion. Such statements have no significance if unaccompanied by data as to the prevailing stages of water. These matters are brought out in Section E—1, Appendix C, where many photographs illustrative of the facts are presented. The injury already done, which is not extensive, would be repaired by the proposed remedial works. The effects of diversion on the Whirlpool and Lower Rapids are beneficial up to a certain point, the spectacle being greatest at moderately low river stages.

66. *Allowable diversion around the Falls and rapids.*—If the remedial works whose design has been outlined above are provided, it is believed a total diversion of 80,000 cubic feet per second may be made around the Falls, and 40,000 around the Whirlpool and Lower Rapids without injury to the scenic beauty, and without endangering the ice discharging capacity of the Falls or rapids, these diversions to be divided equally between Canada and the United States.

- After these diversions have been effected it is quite possible that observation will show that further diversion is permissible, especially should the possibility of utilizing further diversions at medium or high stage only be considered.

67. The quantities stated in the preceding paragraph were arrived at after considerable study, as related in Appendix C. The effects at low-water stages are the critical considerations. Under the very infrequent condition when the total river flow is 130,000 cubic feet per second the flow over the Falls would be 50,000 cubic feet per second, of which 5,000 would pass over the American Falls. The flow over the Horseshoe Falls would then be about twice as large per foot of crest line as the flow over the American Falls under average conditions, and more than three times as large as during this very abnormal low-water condition. The 45,000 cubic feet per second flowing down the rapids above Horseshoe Falls would provide 50 per cent more water per foot of width of channel than past experience has shown necessary in the American channel leading to the American Falls for the prevention of ice jams. The possibility of dangerous ice jams forming in the Whirlpool Rapids or Lower Rapids appears much greater than in the rapids above the Falls. It is important also that the scenic beauty should not be injured at very low stages. A careful study of photographs, profiles, gauge records, and other evidence leads to the conclusion that the diversions around these rapids should be limited to 40,000 cubic feet per second until the effects of this diversion can be observed.

68. *Propositions for utilizing diversions with greater economy.*—It is in the realm of power development that great opportunities lie for the more economical use of water diverted from the Great Lakes, and these opportunities are greatest, and of most importance at Niagara Falls. Of the 20,000 cubic feet per second permitted by treaty to be diverted from Niagara River on the United States side above the Falls, 500 is now allotted to the Hydraulic Race Co., of Lockport, and 19,500 to the Niagara Falls Power Co. of Niagara Falls, N. Y. The 500 cubic feet per second delivered to Lockport is used inefficiently and intermittently. As yet the Niagara Falls Power Co. does not use all of its allotted water and of that a part is not yet utilized efficiently. On the average about 17,290 cubic feet per second are used to develop 245,000 horsepower. This company is now extending its plant under authority of the department, and in partial compliance with recommendations embodied in the interim report of March 2, 1918. This extension will contain three large, modern generating units of highest efficiency, totaling 100,000 horsepower, and will make possible use of the full 19,500 cubic feet of water per second, and greatly improve the efficiency of the plant as a whole. The head used is that between the Chippawa-Grass Island pool, above the Falls, and the Maid-of-the-Mist Pool, directly below the Falls. With a further extension of the plant operating under this head, and another extension covering the head of Whirlpool and Lower Rapids, this diversion of 19,500 cubic feet per second can be made to produce a total of about 580,000 horsepower.

69. On the Canadian side a diversion of 36,000 cubic feet per second for power development is allowed by treaty. At present it is estimated that 33,325 cubic feet per second are diverted producing 388,570 horsepower, which indicates a poor average efficiency.

70. It is to be recognized that in the matter of determining methods for securing greater economy and efficiency of water diversions, Congress has indicated no apparent intention of delegating decision to the Chief of Engineers or the Secretary of War, but has provided in pending legislation for a special Federal Power Commission to exercise jurisdiction in these matters. Study of methods is however understood to be called for in this report.

71. Several schemes for further development or improvement of present plants at Niagara Falls have been worked out in considerable detail during the course of this investigation. They are presented more fully in Section F, Appendix D, together with outline plans and estimates. What seemed to be the best ideas and suggestions, from whatever source, were utilized. More than 20 other projects which were presented were examined carefully. Data for these studies were obtained largely from surveys for this investigation and partly from the United States Lake Survey and other sources.

72. The fundamental assumptions as to the general character of all the preliminary designs and estimates are set forth in Appendix D. There also are given the unit costs adopted, which were arrived at with special care. The matter of economic sizes of principal parts of the projects was given due consideration. It is important to note that such power developments will now cost probably more than twice what they would have cost under the market conditions of 10 years ago.

73. *Single-stage and two-stage projects.*—The most general division of proposed water-power developments at Niagara Falls is into single-stage and two-stage projects. The former contemplates using the water under a single head of about 310 feet, with the generating machinery all in one station. The latter provides for dividing the total head into two parts at about the level of the Maid-of-the-Mist Pool, using the water first in one station at the side of this pool under a head of about 220 feet, and then again under a head of about 90 feet in a second station situated well down in the Lower Gorge toward Lewiston. A few remarks regarding the relative merits of the two schemes will be presented farther on.

74. *Proposed plant using entire diversion and total head.*—Three types of installation for utilizing in a single stage the entire diversion and total head have been considered. The first provides for a power house somewhere on the upper river with water wheels in a deep pit, the discharge from the wheels passing to the lower river through a tailrace tunnel. The second calls for an intake on the upper river and a tunnel from it to a power house in the gorge of the lower river. The third is similar to the second, except that the tunnel is replaced by an open canal. Plans providing a combination of these ideas are possible, but seem to offer no advantages.

75. *Tailrace tunnel proposition.*—In such a project the most economical location places the intake and power house in Upper Niagara River on or near the shoal just upstream from Grass Island, and the tunnel outfall in the Lower Rapids, not far downstream from the Devils Hole. The location is shown on Plate No. 33, and certain general outlines of the design on Plate No. 34. A summary of the estimate appears in Appendix D. The total estimated construction cost, on the assumptions previously noted, is \$52,220,000. The estimated

total power output is 584,000 horsepower, making the estimated construction cost \$89.40 per horsepower. The estimated time of development is three years for first power and five years for completion.

76. *Pressure tunnel proposition.*—The economic location of this project is much the same as that of the tailrace tunnel proposition, the intake being on Grass Island Shoal and the power house in the Lower Gorge below Riverdale Cemetery. The general plan is shown on Plate No. 33 and outline details on Plates Nos. 35, 36, and 37. The total horsepower developable by this plant at mean stage with 20,000 cubic feet per second would be about 588,000 horsepower. The estimated cost is \$50,803,000, or \$86.40 per horsepower.

77. *Power canal proposition.*—A thorough study of possible routes for a power canal led to the selection of the one indicated on Plate No. 39 as the most economical. It extends from an intake just south of Conners Island to Riverdale Cemetery, just above Fish Creek. A heavy concrete ice diverter is provided across the canal entrance. The power house in the gorge is nearly identical with that of the pressure tunnel proposition. The estimated total horsepower is 591,000, and estimated cost \$43,579,000, making the estimated cost per horsepower \$73.70.

78. *Comparison of preceding projects.*—The above-given estimates show the first cost of the canal proposition lower than either tunnel proposition. The cost of operation and maintenance would be greater, but upon the assumptions in the estimates, not enough to overbalance the difference in fixed charges. The Tailrace Tunnel plan has several inherent disadvantages which make it of very doubtful advisability. These are the expected presence of considerable ground water in the low-level tunnel during construction, the difficulty of unwatering the tunnel in case of accident or needed repairs, and the difficulty of regulating surges in the tunnel. The most important objection to the Pressure Tunnel plan is that it will be necessary to shut down the entire plant for a short time and drain the tunnel in order to repair or remove obstructions from the penstock valves. This difficulty is not regarded as controlling; it could be obviated by extending the tunnel up to a surface fore bay, and using long penstocks, or by other means. The only formidable objections to the Power Canal plan is the presence of an open canal through or near the city, and the uncertain costs of maintenance due to climatic conditions. There is no reason, however, why it could not be made less unsightly than the present canal, and, in fact, even attractive in appearance. It would, however, partially prevent the use of valuable land for other purposes, form a dividing line disadvantageous to street and sewer systems, and cause the city or the company some extra expense for building and maintaining bridges as the city grew. Further consideration and comparison of these propositions are given later when the cost of production of power is taken up.

79. *Proposed plants dividing diversion, but using full head in one stage.*—There seems to be no advantage, but rather a disadvantage in using 20,000 cubic feet per second in two or more plants under the full head rather than in one plant. In case of a total diversion of, say, 40,000 cubic feet per second on the American side in a single stage, the advisability of dividing this into two plants should be given careful consideration. For a canal project one plant would

appear preferable, while for a tunnel project the single tunnel would be too large, making a division into two plants advisable.

80. *Proposed plants dividing diversion and dividing head.*—A number of schemes have been proposed whereby both the head and the diversion were divided between several plants. There seems to be no advantage in any of these as a wholly new plant. Of those which involve the retention of some of the existing plants, only one seemed to merit further consideration. The project involves the retention and use of the present hydraulic canal, and station 3 of the hydraulic plant of the Niagara Falls Power Co., and has been named the "Compound two-stage proposition." The upper stage portion corresponds closely to the project of the Hydraulic Power Co., which has been approved by the department.

81. *Compound two-stage proposition.*—This proposition includes retention and use of present station 3 of the hydraulic plant of the Niagara Falls Power Co., a slight enlargement of the present hydraulic canal by deepening, construction of a tunnel paralleling the canal from Niagara River at Port Day to a new power house just upstream from present station 3, and construction of a long tunnel of large diameter conducting the water discharged from these power houses to a new power house near Riverdale Cemetery, in the Lower Gorge, where it would be used again under a head of about 90 feet. A portion of the upper stage part of this project has been under construction since June, 1918, under authority of the Secretary of War, including deepening the present canal and building a power house near station 3 containing three generating units of approximately 33,000 horsepower each. Note is made of the fact that plans and estimates have been modified from time to time so that the outline plans and estimate herein presented do not correspond exactly either to those submitted in the interim report or to those now in force at the Niagara Falls Power Co., successor to the Hydraulic Power Co. The question of using the water released from the Niagara Falls plant in a single development instead of as a part of the compound two-phase development under the approved plan is being considered by the Niagara Falls Power Co.

82. The general outlines of the plans herein presented are shown on Plates Nos. 33, 42, and 45. The estimated cost of the upper stage improvement is \$21,183,000, which represents a cost of \$51.80 per horsepower for the total power then available under the upper stage. The estimated time of development is three and one-fourth years for completion.

83. The lower stage portion of the plant consists of a large tunnel extending from the powerhouses on the shore of the Maid-of-the-Mist Pool to the Lower Gorge at Riverdale Cemetery, a power station at the lower end of the tunnel, and a large spillway just upstream from the lower powerhouse. The estimated cost of the lower stage plant is \$34,298,000, and the estimated total horsepower is 164,000, making the cost per horsepower \$209.10.

84. There are several reasons why it is preferable to take the water for the second stage development directly from the upper stage powerhouses rather than to permit these latter powerhouses to discharge into the Maid-of-the-Mist Pool and then to divert the water from this pool near the railroad bridges, thus saving

about one mile of tunnel length. The first reason is, it will avoid trouble with ice which would undoubtedly be very serious in the Maid-of-the-Mist Pool; second, it will prevent the great losses in power, reduction in efficiency, and difficulties of operation arising from the large range of stage of this pool; third, it will avoid the costly and difficult construction of an intake which would have to be carried down deep to provide against being unwatered when the pool is lowered by diversions of water around the rapids; and fourth, it will avoid again separating trash and weeds from the water.

85. For the entire combined plant of the compound two-stage proposition the estimated cost is \$55,481,000. The power then available will be about 573,000 horsepower, making the cost \$96.80 per horsepower for the power then available.

86. The critical element of this scheme is the operation. By means of relief valves, and a by-pass at the upper plant, and also by proper electrical interlocking of circuit breakers and controls, it must be positively assured that the supply of water to units operating at the downstream powerhouse does not fail in order to prevent great danger of damage at the lower station.

87. *Proposed plants using full diversion but dividing head.*—A two-stage proposition independent of the old power developments was planned in outline, as shown on Plates Nos. 33, 46, 47, and 48, and was named the "Simple two-stage proposition." Its upper stage part is much like the upper stage tunnel portion of the compound two stage proposition, while the lower stage portions of the two propositions are almost identical except in length of tunnel. The cost of the full development is estimated at \$61,227,000, the total horsepower at 580,000, and the cost per horsepower at \$105.60. The estimated time of completion of this project is four and one-half years for the upper stage and four and one-fourth for the lower stage. They might be built simultaneously or separately, as desired.

88. *Proposed power development combined with ship canal.*—In an earlier part of this report, under the caption, "Proposed navigation canals, Lake Erie to Lake Ontario," mention was made of various routes for a canal in United States territory connecting Lakes Erie and Ontario, which have been proposed during the past 100 years or more, and the fact was brought out that the La Salle-Lewiston route proposed by the United States Board of Engineers on Deep Waterways in 1900 still offers the greatest advantages for such a waterway and the lowest cost. The estimates given in these earlier paragraphs cover a navigation canal only. The La Salle-Lewiston route offers the greatest advantages also for a combined power and ship canal. In order to provide for a diversion of 20,000 cubic feet per second for power through such a canal without dangerously high currents, it is necessary to make the cross section much larger than is necessary for the ship canal which provides for no power development. The cross section proposed is 400 feet wide by 30 feet deep in shallow cuttings, and 300 feet wide by 40 feet in deep cuttings. The mean current in such a canal would be 2.3 miles per hour.

89. Under the plans presented in Appendix D, and on plates Nos. 49 to 51, the water for power generation is taken from the side of the ship canal about 3,000 feet above the upper locks through a long row of submerged arches piercing a massive concrete wall. From the inlet bay behind the arches a short-power canal conducts the water to a

fore bay at the edge of the bluff just downstream from Riverdale Cemetery. The power house in the Gorge is similar to that of the power canal proposition. The estimated cost of the entire project is \$198,412,000, which is \$324.70 per horsepower for the estimated total capacity of 646,000 horsepower. The cost of the part necessitated for power purposes, including excavation of the excess cross section of canal, is estimated at \$93,000,000, or \$97.50 per horsepower. The time of construction is estimated at 8 to 10 years.

90. The combined ship and power canal, described above, is estimated to cost \$19,833,000 more than the sum of the costs of a 200-foot ship canal for navigation only, and the power-canal proposition previously described; and to produce 20,000 more horsepower.

91. *Plants proposed by various interests.*—Careful consideration has been given to projects presented by the Hydraulic Power Co., Niagara Falls Power Co., Empire Power Corporation, Hugh L. Cooper & Co., Leonard H. Davis for Union Carbide Co., Niagara Gorge Power Co., T. Kennard Thompson, and others. Many of these projects are of great merit, while others appear to have little or none. Brief descriptions and comments are given in Appendix D, section F 9. It is believed that there is nothing of particular value in the projects which is not embodied in the various propositions already presented, some of the ideas already presented having come directly from the propositions submitted by the parties named above in this paragraph.

92. *Comparison of proposed developments.*—The costs given in the preceding paragraphs covering the various projects do not include the entire capital costs, nor even the whole of what might be termed construction costs. Thus the general overhead items, properly part of construction costs, which have been omitted in each case, are costs of promoting interest in the proposition, of obtaining funds, of organizing a managing company, and of legal services involved in promotion, financing, and organizing. The fundamental item of purchase of any necessary rights from existing power companies has not been included. The development expense involved in building up a market for power consumption, and making the enterprise a going concern, also properly a part of capital cost, has been omitted. The costs given are called construction costs. They include purchase of necessary land and rights of way, and construction required in providing a plant to produce electric energy at generator voltage on the bus bars of the power station. All expense pertaining to transformation and transmission of electric energy has been omitted.

93. The omissions just mentioned have appreciable effects on the capital cost of each proposition, and are unequal in their effects on different propositions. There are differences in the probable operating costs also. To make a comparison of the propositions which takes into account in so far as possible the differences thus arising, an estimate has been made of the cost of producing power in each case.

94. Any proposition except the compound two-stage, could be made a development of a second 20,000 cubic feet per second, the first 20,000 second-feet having been developed, under a two or more permittee cooperation plan. Assuming a load factor of 90 per cent and a power factor of 90 per cent and omitting fixed charges on the original overhead expenses and also fixed charges on the original development

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expense, the cost per horsepower per annum on the bus bars in the power station is estimated as shown in Table No. 4:

TABLE NO. 4.—*Power development by second diversion of 20,000 cubic feet per second.*

No.	Proposition.	Estimated cost per horsepower per annum.
1	Power Canal (par. 77).....	\$10.00
2	Pressure Tunnel (par. 76).....	11.20
3	Tailrace Tunnel (par. 75).....	11.60
4	Simple two-stage (par. 87).....	13.94

These are rough estimates only, and are not as accurate as the construction cost estimates previously given, being based on less reliable data. They serve, however, to indicate the relative advantages of the different propositions and are believed to be worthy of careful consideration. They are probably all much lower per horsepower per annum than the ultimate actual cost of delivering power on the premises of the most favorably situated customer, because of the items of cost which have not been included.

95. It is to be assumed that it might be desirable to adopt a one-or-more-permittee independent plan, under which the first diversion of 20,000 cubic feet of water per second is to be regarded as not developed. In such case any one of the propositions might be employed, but the costs would necessarily be increased by the amount required to compensate any interests involved. With this condition added to the assumptions involved in table No. 4, production costs have been estimated as shown in table No. 5.

TABLE NO. 5.—*Power development by first diversion of 20,000 cubic feet per second.*

No.	Proposition.	Estimated cost per horsepower per annum.
1	Power Canal (par. 77).....	\$14.90
2	Pressure Tunnel (par. 76).....	16.30
3	Tailrace Tunnel (par. 75).....	15.70
4	Simple two-stage (par. 87).....	18.00
5	Compound two-stage (par. 81).....	17.00

The comments with regard to Table No. 4 apply with equal force to Table No. 5.

96. *Two-stage versus single-stage project.*—As regards financing, a two-stage development has a decided advantage over a single-stage development in that only the upper stage need be developed at first, nearly two-thirds of the total ultimate power being provided at about half the total ultimate cost. This is approximately true of either the compound or single two-stage propositions, in lessening the capital cost for the time being and thus keeping down the fixed

charges. Moreover, first power could be produced sooner, and less unproductive expenditure would have to be carried. This would lead to a sounder financial condition during construction; and so, probably, to the flotation of bonds on better terms.

97. The matter of fixed charges due to costs of promotion, organization, purchase of rights, development of market, and going concern, enter into the question of financing to an extent not predeterminable.

98. In discussing the various propositions, the production cost only has been dwelt upon. A chance for profit is essential to the best interests of such an enterprise in order to induce men to undertake the risks involved, and to spur them on to their best endeavors. As regards profits, and the accumulation of an undivided surplus available for reinvestment in the development, during the period of construction, the two-stage plan is superior to the single-stage plan.

99. *Effect of rate of power absorption.*—In comparing the relative merits of the single-stage and two-stage propositions, a very important consideration is the effect of rate of absorption of power. By rate of absorption of power is meant the total quantity of power which will be demanded and used in any year, over and above what was used in the preceding year. The estimates heretofore given were based on wartime demands for power, assuming that any power developed at Niagara Falls would find immediate use in industry as soon as it was produced. The peace time rate of absorption in the past has been less than half as great. When power is absorbed less rapidly, construction interest ultimately amounts to more. In this respect the two-stage plan is decidedly superior to the single-stage plan, and the advantage increases as the rate of absorption of power decreases.

100. *Comparison of ultimate incomes.*—What a hydro-electric generating station has to sell is electric energy, expressed in kilowatt-hours, horsepower hours, or horsepower-years, and the ultimate number of kilowatt-hours produced is a measure of the ultimate income obtained. The two-stage proposition has an advantage, during the first few years after construction is commenced, over the single-stage proposition, because power is produced so much sooner. As time goes on, however, the single-stage production overtakes and surpasses, the two-stage production unless the rate of absorption of power is very low. If this comparison is made on the basis of total amount of energy produced per dollar of construction cost, the power canal proposition overtakes the compound two-stage proposition in 13½ years, and thereafter surpasses it. Such comparisons are dependent on the various items of the estimates of cost and time of development, and are of little value for the reason that the computed time in which one will overtake the other varies a great deal with comparatively slight changes in these estimates.

101. *Summary of comparison of single-stage and two-stage propositions.*—To sum up the comparison of the single-stage and two-stage propositions:

There is shown in favor of the single-stage proposition—

1. Lower construction cost per horsepower.
2. Lower unit cost of power production.
3. Greater total financial return per dollar invested, except in case absorption of the power developed takes place at a very slow rate.

There is shown in favor of the two-stage proposition—

1. Increasing advantage as rate of power absorption decreases.
2. Superiority of compound two-stage proposition at very low power absorption rate.
3. Easier financing.
4. First power produced sooner.
5. Better credit maintained.
6. Total return from sale of power greater for first few years.
7. In case of suspension of construction activities before completion there would be (a) smaller capital cost per horsepower produced; (b) less unproductive expenditures carried.

102. The foregoing analysis indicates that for utilizing the present authorized diversion of 20,000 cubic feet of water per second from Niagara River there is very little to choose between the compound two-stage proposition and the power canal proposition.

103. The study further shows that for a second development, designed to utilize an additional and similar diversion of 20,000 cubic feet per second, a power canal proposition similar to that presented is less costly than any other.

104. The power canal proposed would not be navigable, and it could not properly be made a part of a navigable waterway. No combination of power development with navigable canal from upper to lower river is justifiable on the basis of power production. The La Salle to Lewiston route is the best for a ship canal. It would be cheaper to construct this canal of 200-foot width and 30-foot depth for navigation use only, and also construct the canal for power purposes only, than to construct the combined power and ship canal. (Par. 90.)

105. Previously in this report, it has been pointed out that 40,000 cubic feet of water per second may safely be diverted around the Whirlpool and Lower Rapids, this being the total for both sides. The wisdom of diverting any more in the light of the present knowledge is doubted, and it is felt that this amount should be diverted first, and observation of the resultant effects noted before further diversions are permitted. It was also pointed out that at least 80,000 cubic feet of water per second might be diverted around the Falls from the Chippawa-Grass Island Pool to the Maid-of-the-Mist Pool, this latter diversion being permissible only on condition that adequate remedial works be constructed just above Horseshoe Falls.

106. In dealing with the question of the development of power at Niagara Falls the purpose of this report has been to so present the actual conditions as they exist, the possible solution of the problem as deduced from those conditions and the solutions presented by interested parties independently, as to enable the constituted authority to take such action either on the whole subject or any one phase of it, as may seem best.

107. *Effects of diversions upon lake levels.*—It is well understood by engineers who have studied the question, that each of the Great Lakes constitutes a natural storage basin discharging through an outlet, and that any increased flow of water from the basin through an enlarged original outlet, or through a new outlet, causes a lowering of the lake surface. Such increased flow is a diversion of water from the lake. The amount of lowering can not be measured directly by water gauges on the lakes, as the elevation of the lake surface is subject to constantly varying fluctuations due to various other causes.

If, however, the laws governing the discharge of the connecting rivers are known, the amount of lowering can be computed by simple mathematical processes. These discharge laws have been determined by the United States Lake Survey from a long series of measurements on the outflow rivers.

108. *The outlets on the lakes.*—The outlet of Lake Superior is through the St. Marys River. The natural flow of this river has been changed by the construction of the piers of the International Railroad Bridge, by filling in along both shores, by the construction of canals and locks on both sides of the river, by the diversion of water for power development, and by the construction of regulating works. At the present time only about 25 per cent of the original cross-section of the rapids and 33 per cent of the discharging capacity is open to free flow. Present plans and construction contemplate further extension of the regulating works to the full width of the open river. When these are complete the outflow from Lake Superior will be brought under full control.

109. The natural outlet of Lakes Michigan and Huron is through the St. Clair River. This river has but little fall, and the discharge from the lake depends not only upon the elevation of Lake Huron but also upon that of Lake St. Clair, which in turn is affected by changes in the elevation of Lake Erie. There appears to have been no important change in the regimen of this river during the last 24 years.

110. Lake St. Clair discharges through the Detroit River. This river is of the same type as the St. Clair and its flow depends upon the elevations of Lake St. Clair and Lake Erie. Comparatively few discharge measurements have been made on this river, and its hydraulic relations are not as accurately known as those of the other rivers. There is some evidence that a change in the regimen of this river occurred about 1890. Another change was made by the building of the Livingstone Channel cofferdam in 1908. When the cofferdam was opened in 1912 it was found that the remaining portions of the dam and the various dumps compensated for the excavation of the channel, and the discharge laws were the same as before the cofferdam was built.

111. The Niagara River is the natural outlet of Lake Erie. The discharge of this river depends upon the elevation of Lake Erie, but is modified somewhat by the diversion of water from the river itself. Only very minor changes in the regimen of this river have occurred in recent years.

112. The natural outlet of Lake Ontario is through the St. Lawrence River. The controlling section is the Galop Rapids, the discharge of which is governed by the elevation of Lake Ontario. Various works in connection with the Canadian improvements to navigation have altered the regimen of these rapids materially at different times. Since 1903 conditions have remained constant.

113. The discharge equations of all these rivers have been determined by the United States Lake Survey, and are presented in Section G 2 of Appendix E.

114. *Effect of ice on river flow and lake levels.*—The equations for determining the flow through the various connecting rivers of the Great Lakes system apply only during open season conditions. During the winter months, when there is more or less ice in the rivers, the

flow is retarded, this retardation amounting in some of the rivers at times to as much as 50 per cent of the normal flow. During the three winter months the flow of the St. Marys River is retarded on the average to the extent of about 2,800 cubic feet per second. The effect on Lake Superior is only a few hundredths of a foot.

115. On the St. Clair and Detroit Rivers the effects of ice are more serious. Jams or blockades are of frequent occurrence, and at times hold back large quantities of water. The estimated effect for the two rivers is a reduction in the yearly mean flow amounting to about 10,000 cubic feet per second. The effect is to raise the level of Lake Huron during the winter months and lower Lake Erie. During the summer an increase in the river flow results which tends to restore the normal levels, but before equilibrium is attained another winter intervenes, and thus Lake Huron is maintained at a higher level than it would be if no ice were formed.

116. The ice effect on the Niagara River is not very well determined, but is known to be quite small. The estimate is that it keeps the yearly mean stage of Lake Erie about seven-hundredths of a foot higher than it would otherwise be.

117. On the St. Lawrence River a good deal of data as to the ice effect is available. The total ice effect is estimated to be equivalent to a reduction of 4,400 cubic feet per second in the yearly mean discharge. This leaves Lake Ontario high in the spring, but owing to the small area and large outflow of the lake, normal conditions are practically restored before the following winter.

118. The question of ice effect has not always been well understood, and its incorrect treatment has in the past often led to erroneous conclusions regarding the hydrology of the Great Lakes system. An admirable analysis of these effects is given in section G3 of Appendix E.

119. *Hydrological data.*—An analysis of the hydrology of the Great Lakes was made. This was based on extensive rainfall records of the United States and Canada, the stream run-off reports of the United States Geological Survey and the Hydro-Electric Power Commission of Ontario, and the river discharge measurements and water gauge records of the United States Lake Survey. - The net supply for each lake was computed for the period 1905-1914, inclusive, and from this the outflow during the same period was subtracted. The result was the evaporation from the lake surface. These evaporation values are reasonably consistent among themselves, and agree with the meager evaporation data available. This indicates that the adopted discharge formulas are consistent, and that there are no gross discrepancies or omissions in the hydrologic data.

These studies are described and the results tabulated in section G 4 of Appendix E.

120. *Effects of present diversions.*—The ultimate effect of diversions upon the levels of the lake from which they are drawn is a function of the rate of diversion and of the law of discharge through the main outlet. When these are known the lowering effect of the diversion can be computed. The discharge laws are well determined from the lake survey measurements, and the rates of diversion have been carefully estimated from all the available data. Using these quantities the effects on the different lakes have been computed for high, mean, and low stages of the lakes.

121. With conditions as they were in 1896, Lake Superior would have been lowered nearly 3 feet by the present diversions for power and navigation. That the surface has not been so lowered is due to various obstructions placed in the rapids, including the controlling works. It is expected that when the controlling works are completed, and the several power canals are enlarged to ultimate proposed capacity, the needs of navigation can be served, a minimum of 60,000 cubic feet per second can be used for power, and the level of Lake Superior can be regulated within a maximum range of 2.5 feet, and ordinarily within a range of 1.5 feet, or between elevations 602.1 and 603.6.

122. The only diversion from Lake Michigan-Huron which has any important effect upon lake levels is that of the Sanitary District of Chicago. This diversion through the Chicago Drainage Canal amounts to a yearly average of about 8,800 cubic feet per second. An ultimate diversion of 14,000 cubic feet per second through this canal and through the Calumet-Sag branch, now under construction, is contemplated. The diversion at Chicago causes a lowering of all water levels from the lower sills of the locks at Sault Ste. Marie to tide water in the St. Lawrence River. The amount of lowering caused by the present diversion at mean stage is shown in table No. 6.

TABLE No. 6.—*Lowering in feet at mean stage due to present diversions of water from the Great Lakes.*

Diversion.	Amount, in cubic feet per second.	Mich- igan- Huron.	St. Clair.	Erie.	Niagara River at Chippa- pawa.	Ontario.	St. Law- rence River at Lock No. 25.
Chicago Drainage Canal.....	8,800	0.43	0.35	0.41	0.23	0.42	0.62
Welland Canal.....	4,500	.03	.09	.21	.12		
Black Rock Canal.....	700		.01	.03			
New York Barge Canal.....	1,000			.01	.03		
Niagara power companies.....	50,885	.01	.05	.10	.60		
Total.....		.47	.50	.76	.98	.42	.62

123. From Lake Erie the Welland Canal diverts about 4,500 cubic feet per second, and the Black Rock Ship Canal about 700 cubic feet per second. These diversions lower Lakes Michigan, Huron, St. Clair, and Erie. At Niagara Falls six different companies use water for power development. Some of these cause a lowering in Lakes Michigan, Huron, St. Clair, and Erie, while others, which divert water below the first cascade, have only a local effect. The amount of these lowerings is given in Table No. 6.

124. There are no diversions from Lake Ontario or the upper St. Lawrence River except a small amount for the Canadian canals. The building of the Gut Dam in 1903 has permanently raised these waters by about 0.56 foot. Below the Galop Rapids there are several diversions which cause local lowering in certain parts of the St. Lawrence.

125. The whole matter of the effects of present diversions upon lake levels is treated in Section G 5 of Appendix E.

126. *Effects of proposed diversions.*—The effects of the proposed increases in the diversions at Sault Ste. Marie will be completely

neutralized by the operation of the completed controlling works. At Chicago the proposed increase of the diversion to 14,000 cubic feet per second would increase the present lowering by more than 50 per cent. The completion of the new Welland Canal and the increased use of the Barge Canal will cause farther lowerings. If the diversion at Niagara Falls be ultimately increased to 80,000 cubic feet per second and no compensating works provided, there would be a very large lowering of the river, and a notable amount in the lakes above. The computed lowering at mean stage which would result from the various proposed diversions is shown in Table No. 7.

TABLE NO. 7.—*Effect in feet at mean stage of proposed diversions from the Great Lakes.*

Diversion.	Proposed increase.	Lakes Michigan and Huron.	Lake St. Clair.	Lake Erie.	Niagara River at Chippawa.	Lake Ontario.	St. Lawrence River at Lock No. 25.
Chicago Drainage Canal.....	5,200	0.25	0.21	0.23	0.13	0.24	0.37
Welland Canal.....	1,000	.01	.02	.05	.03	.....	.....
New York Barge Canal.....	700	.....	.....	.01	.02	.....	.....
Niagara power companies.....	48,000	.03	.10	.22	1.25	.....	.....
Total effect of proposed increases.....		.29	.33	.51	1.43	.24	.37
Total effect of present diversions.....		.47	.50	.76	.98	.42	.63
Grand total.....		.76	.83	1.27	2.41	.66	.99

This matter is treated at greater length in section G 6 of Appendix E.

127. *Remedial works.*—These lowerings of the lake levels cause a serious loss to the navigation interests and the general public, the nature and amount of which is discussed later in this report. The restoration and maintenance of the natural levels therefore becomes a matter of importance.

128. There are three general methods by which a restoration of depths on the lakes may be sought—first, the deepening of all harbors and channels affected by the artificial lowering of water levels; second, the construction of regulating works in the outlets of the lakes to raise the levels of the lakes and to control their elevations within fixed limits; third, the contraction of the outlets by means of fixed obstructions which will raise the levels of the lakes without greatly affecting their natural fluctuations.

129. The first method is considered altogether too expensive, and has other unsatisfactory features. It is recommended only for a few special cases. The second has frequently been proposed, but upon investigation it is found to be less simple than it appears. It involves obstructions to navigation and difficulties with ice. Moreover, it has been shown that efficient regulation of one lake tends to aggravate the fluctuations of those below it. This system has been adopted at the Soo, where circumstances are particularly favorable to it, but its suitability for the lower lakes is problematical. The third method is the cheapest and simplest, and is considered the most desirable. It is already operating successfully in the case of the Gut Dam.

130. In section G 7 of Appendix E the works needed at various places to compensate for the effects of all diversions, present or prospective, are considered in some detail. It is concluded that the project is entirely feasible and that the expense will not be excessive in view of the benefits received. The works involved include wing walls or other methods of narrowing the channels at the head of each of the St. Lawrence Rapids, a long submerged rock weir above the rapids at Niagara Falls, and a series of such weirs near the head of the Niagara River and in the upper reaches of the St. Clair River. To effect the required deepening in Lake St. Clair and at the head of the Detroit River it was thought that dredging would be most satisfactory.

131. The design of these works suggested above must be preceded by extensive surveys and studies. The building of models on a fairly large scale for experimentation prior to final adoption of designs appears desirable. The construction of the final works should be preceded and accompanied by the maintenance of a number of automatic water gauges at critical points on the rivers. It is highly desirable that these gauges be installed as soon as possible in order that several years' records may be available before construction is commenced.

132. *Economic effect of diversions upon navigation.*—The Great Lakes system forms one of the world's greatest highways for waterborne transportation. The Great Lakes fleet moves more than 100,000,000 tons of freight each season. The greater part of this commerce is in the so-called "bulk freight," consisting of iron ore, coal, grain, and limestone. This is carried in a peculiar type of vessel known as the "bulk freighter." The bulk freighters are highly specialized boats which have been developed by the conditions of the lake trade. These vessels are from 280 to 625 feet in length and have a carrying capacity of from 3,000 to 15,000 short tons. Most of them can be loaded to a draft of about 22 feet. They are the most economical carriers in the world, their rates usually being less than one-tenth of a cent per ton-mile, and sometimes only a third of that amount. Rail rates are several times as much, often being at least 10 times the water rates. The annual saving over the cost of moving this same freight by rail exceeds a quarter of a billion dollars.

133. Under the conditions of 100 years ago, the only ships which could navigate the Great Lakes system and enter the harbors were small vessels drawing about 5 feet of water. The United States has spent about \$135,000,000 in improving the harbors, deepening and straightening the channels, and building locks on the St. Marys and Niagara Rivers. The Canadians have done similar work on a smaller scale. As a result there is now available a ship channel through and between the upper lakes with a controlling depth of 21 feet at mean stage. All the important harbors have corresponding depths. From Lake Erie through the Welland Canal, Lake Ontario, and the St. Lawrence River to tidewater at Montreal, the controlling depth is 14 feet.

134. The immense traffic of the Great Lakes is a direct result of these improvements of navigation, and the movement of such large amounts of freight at such low rates is directly due to the greater

depths thus made available. Vessel owners keep close track of the stage of water, and take advantage of every period of high stage to load their boats to greater draft. During times when low stages prevail they are correspondingly handicapped and the carrying capacity of the fleet is materially reduced.

135. As already shown, the existing diversions of water from the Great Lakes have caused a considerable lowering of the lake levels, and further diversions, with consequent further lowerings, are contemplated. The average loss caused by a reduction of one-tenth of a foot in the available draft amounts to \$44.57 for one trip of a bulk freighter on the upper lakes, or \$590,000 per year for the whole fleet. For the smaller vessels engaged in trade through the Welland and St. Lawrence Canals the average loss caused by a lowering of one-tenth of a foot is \$41.40 for each trip and \$70,000 per year for the whole fleet.

136. The amounts by which the various lakes have already been lowered by existing diversions have been given in Table No. 6. The total loss to the bulk freight trade caused by this lowering is estimated at \$4,713,000 per year. If all the contemplated diversions listed in Table No. 7 should be effected the resulting lowering would increase the annual loss to \$7,825,000.

137. Of the loss now occurring, \$2,866,000 per year is due to the diversion of 8,800 cubic feet per second by the Sanitary District of Chicago. This is 60 per cent of the total loss and is \$326 per year for each cubic foot per second of diversion. The diversion of the power companies at Niagara Falls taking water from points above the first cascade, equivalent in effect to the diversion of 23,000 cubic feet per second from the Chippawa-Grass Island Pool, causes an annual loss of \$526,000. This is 11 per cent of the total loss and is \$23 per year for each cubic foot per second of effective diversion.

138. The total loss to navigation amounts to a direct tax upon the transportation of iron ore, coal, and grain—that is, upon steel, fuel, and food, three fundamental necessities of modern life. The Great Lakes traffic is an absolutely essential part of the American steel industry, and plays an important part in the distribution of grain and coal. The bulk freighter of the lakes carries each year about 80 per cent of the Nation's production of iron ore, more than 20 per cent of the combined wheat crops of the United States and Canada, and about 5 per cent of the coal production of the United States. The cost of all these products to the general public is increased by the diversions.

A thorough study of this subject is presented in Appendix H, Section I.

139. *Effect upon riparian interests.*—The effect of diversions of water from the Great Lakes upon riparian interests on these lakes and their connecting waters is small. The lower lake levels uncover a slightly greater width of beach, but this is usually neither an advantage nor a disadvantage to the riparian owner. In a few places, notably on Maumee and Saginaw Bays and at St. Clair Flats, there is lowland which is somewhat increased in value when low stages of the lakes permit the harvesting of marsh hay. There is also a small amount of low-lying land which is very valuable for truck gardening, but is so low that in years of high stage it is too wet for use.

Any lowering of the lake levels works to the advantage of the owners of these lands.

140. In the sheltered waters of the Great Lakes the lowering of water levels works serious hardship to many of the riparian owners. In such places there are a great many boathouses, dredged slips, and small private docks. These are built to suit the prevailing stages of the lake, and their value is much impaired at low stages.

141. With the data at hand it is impossible to evaluate these various advantages and disadvantages of the effects of diversions. The experience of the War Department has been that many more complaints are received because of low stage than because of high. It is believed that this matter of riparian interests constitutes but a very minor part of the problem of lake levels. It is discussed in somewhat greater detail in Section H 2 of Appendix F.

142. *Value to Chicago of its diversion.*—In Section B 3 of Appendix F the question of the value to Chicago of its diversion is treated. There are no unbiased data covering this matter in existence, and the estimates herein given are based upon the testimony of the expert witnesses of the Sanitary District of Chicago in the case of the United States *v.* the Sanitary District of Chicago. The *ex parte* nature of this testimony is at least partly counteracted by the rise in wages and prices which has occurred since these witnesses made their studies.

143. The general estimate arrived at was that the present diversion of 8,800 cubic feet per second has a value to the city of Chicago of about \$7,000,000 a year, or \$800 per cubic foot per second per annum.

144. *Value to the public of the effect on power production.*—The various diversions which are used to develop electric power, produce power at a much lower cost than is possible with plants developing power from coal. It is estimated that a new, 300-foot head plant at Niagara Falls could sell large blocks of continuous power at the switchboard at generator voltage for \$19 per horsepower-year, while a steam-electric station of the most modern type would have to charge \$50.70 for the same class of power. The saving by the use of hydraulic power is \$31.70 per horsepower-year, or \$834 a year for each cubic foot per second diverted.

145. The present Niagara developments are less efficient than those proposed and develop much less power from a given diversion. The value of the water which they now divert is estimated at \$500 per cubic foot per second, or about \$25,000,000 a year for the total diversion of the five companies at the Falls.

146. In addition to this saving of money, there is a further value in the conservation of the coal supply of the Nation, and in the great impetus which cheap power gives to the various electro-chemical industries.

147. The other power diversions on the Great Lakes have a value similar in nature, but less in amount, than those at Niagara Falls.

148. *Comparison of effects and values.*—The various studies presented in the earlier parts of Section H show that the present diversion of 8,800 cubic feet per second through the Chicago Drainage Canal has an estimated value to the people of the Sanitary District of Chicago of perhaps \$7,000,000 a year. This diversion damages some riparian interests and is of value to others. On the whole,

riparian interests are probably more damaged than benefited. The damage to the shipping trade of the Great Lakes is estimated at \$2,866,000 a year.

149. It appears that at present the total benefits derived from the diversion exceed the total damages about in the ratio of 5 to 2, but unfortunately the benefits and damages are not received by the same people. It is no satisfaction to the one who is injured to be assured that some one else is benefiting in a greater degree. A reasonable expenditure by the Sanitary District for compensating works will be sufficient to remedy nearly all the harmful results in so far as navigation interests are concerned. Complete estimates of the cost of compensation were not made, but \$500,000 a year should certainly be sufficient to care for compensation for the Chicago diversions for the next one or two decades. If the time comes, however, as it may in 20 or 30 years, when the diversions at Niagara Falls are limited because of the lack of water in Niagara River, the value of water at Niagara Falls will have to be charged against the Chicago diversion. This has been given as \$834 per cubic foot per second per annum, the value to Chicago being only \$800. How these values would change during the next 20 or 30 years is a matter of speculation, but it seems reasonable to suppose that the value of coal will increase, making water power more valuable, while advancements in sanitary science will render the use of water for sewage dilution less urgent, and hence less valuable. A similar case may arise in connection with St. Lawrence power developments. It thus appears that in due course of time the value of this diversion per cubic foot per second is likely to be much greater than at present for power uses along the Niagara and St. Lawrence Rivers than for sanitation at Chicago and power development in Illinois.

150. In case of the Niagara diversions the beneficial results of the diversion are three or four times as great, while the damage done is only one-fifth as much. The estimated figures are—benefits, \$25,000,000 per annum; damages, \$526,000 per annum. The annual cost of compensating for the effect of these diversions is only a few thousand dollars.

151. The other diversions are of minor importance. In each case the damage done is small and the estimated cost of compensation is small. This cost could easily be borne by those who receive the benefit of the diversion.

152. The adjustment of these conflicting interests hinges mainly on the settlement of the long-continued dispute about the Chicago diversion. On the one hand are the needs of our greatest inland city under its present system of sewage disposal. On the other hand are all the riparian, power, and navigation interests of Lakes Michigan, Huron, St. Clair, Erie, and Ontario and also of the St. Marys River below the locks, and the St. Clair, Detroit, Niagara, and the St. Lawrence Rivers. The Sanitary District does not dispute the fact that other sanitary measure can be adopted, and that other lake cities not situated near the summit of a divide are being driven to adopt them; it argues only that the expense is enormous and prohibitive. The Sanitary District no longer denies injury to navigation on the lakes, and to riparian owners, including those along thousands of miles of lake and river shores in Canada; it claims

only that the actual injury is comparatively slight, and much less than the amount claimed by the Federal Government.

153. If conditions could be restored to those existing in 1890, and the city of Chicago should ask permission to divert water for use in such a sewage disposal system as they now have, the request would and should be refused. It would undoubtedly appear that the benefits to be obtained would not be commensurate with the damage which would be caused. If the question were to be decided solely on the basis of the most economical use of the waters of the Great Lakes the solution would involve restriction of the diversion to the amount required for purposes of navigation, and adoption of other methods of sewage disposal.

154. Unfortunately the matter can not be disposed of in such simple manner. The vast sums of money invested by the district demand some protection, and the city can not properly be deprived of its dilution water until some other method of protecting its water supply has been provided. It might be possible, under Congressional sanction, to arrange a program for the gradual reduction of the diversion and retiring of the bonds, together with a corresponding development and substitution of a system of sewage disposal by screening, filtration, sterilization, and similar processes.

155. Another solution would be the authorization of a permanent diversion through the Drainage Canal sufficient in amount to satisfy the present needs of the disposal system, the district agreeing that this amount would never be increased and that the needs of the future growth of the city would be satisfied by some different method. Consideration should be given to the fact that under the existing system a diversion of nearly 10,000 cubic feet per second is occasionally required to prevent the run-off from violent storms from entering the lake, with consequent pollution of the water supply. Under this plan the district would be required to pay for the construction, operation, and maintenance of remedial works which would maintain normal lake levels and prevent the diversion from damaging navigation or riparian interests, thus compensating the paramount interest of navigation; and a license fee should be charged to compensate the general public for the loss of the waterpower which could be developed by the use of this water along the Niagara and St. Lawrence Rivers, this to be based in general upon the difference in the available heads.

156. *International matters involved.*—Previous to the appointment of the International Waterways Commission there was no international supervision of the use of the waters of the Great Lakes. In each country such diversions as were desired were made without consulting the other country, and usually without any thought of the possibility of causing any damage to any one. In the early days most of the diversions were small and the international interests were affected chiefly in theory rather than by the infliction of any actual damage. It is not recalled that either country felt itself aggrieved by any diversion made outside its boundaries.

157. Between 1890 and 1905 this state of affairs was radically altered. The construction of the Chicago Drainage Canal, and of the large power developments at Sault Ste. Marie and Niagara Falls, aroused public interest in the use of lake waters, while the occurrence of unusually low lake stages in the early nineties alarmed

the shipping interests. Studies of the relation between diversion and lake lowering were undertaken by the Government. In 1902 the International Waterways Commission was appointed to consider such matters, and its action resulted in the negotiation of the treaty of 1910 and the appointment of the International Joint Commission.

158. The International Waterways Commission laid down the following general principles applicable to the diversion of water from the Great Lakes:

1. In all navigable waters the use for navigation purposes is of primary and paramount right. The Great Lakes system on the boundary between the United States and Canada and finding its outlet by the St. Lawrence to the sea should be maintained in its integrity.

2. Permanent or complete diversions of navigable waters or their tributary streams should only be permitted for domestic purposes and for the use of locks in navigation canals.

3. Diversions can be permitted of a temporary character where the water is taken and returned, when such diversions do not interfere in any way with the interests of navigation. In such cases each country is to have a right to diversion in equal quantities.

* * * * *

6. A permanent joint commission can deal much more satisfactorily with the settlement of all disputes arising as to the application of these principles and should be appointed.

159. In the above the term "permanent diversions" is understood to mean diversions from the Great Lakes system to some other watershed (e. g. the diversion at Chicago), while "diversions of a temporary character" is taken to mean diversions of water which is returned to the Great Lakes system (e. g. the diversions at Niagara Falls). The term "domestic purposes" is understood to cover all ordinary sanitary uses.

160. To these principles another may well be added, as follows:

Diversions of water from tributaries of the Great Lakes, unless the water is returned to the same tributary, shall be considered as diversions from the lakes.

161. Principle 1 is generally recognized by all the parties interested. Principle 2 is not disputed, but it is coming to be recognized that when such diversions are large they necessitate the construction of remedial works which will prevent any serious lowering of the lake levels being caused by them.

162. Principle 3 has been applied to the diversions at Sault Ste. Marie, and is recognized as a correct general principle. The present treaty with Great Britain, however, makes an exception in the case of the Upper Niagara River and allows a diversion of 36,000 cubic feet per second in Canada and only 20,000 cubic feet per second in the United States. There were good reasons for this discrimination at the time the treaty was framed, but some of them no longer exist and, if the remedial works described in Appendix C are built, the situation will be completely altered and there will remain no reason why an equal division of diversions under principle 3 should not be made.

163. There are Canadian diversions from Lake Erie across the Niagara Peninsula to Lake Ontario, and another one is proposed. Equal American diversions from Lake Erie to Lake Ontario as allowed by principle 3 would be possible, but from an economic standpoint they would be undesirable. For this reason it is felt that no further Canadian diversions of this character should be allowed,

and that the existing diversions should be limited to the present amounts.

164. Principle 6 has been accepted by both countries, and the International Joint Commission has been in existence for several years.

165. The principle that diversions from tributaries be considered to be diversions from the lakes is needed in the interest of clearness. It has usually been followed without comment in discussions of the lake levels problem, but it was not incorporated in the treaty. Without it there is a possibility of frustrating the purpose of the treaty by making large diversions from tributaries in cases where the International Joint Commission would have forbidden them if they were made directly from the lake. In such cases the court procedure provided might well be unsatisfactory to those claiming damage.

166. The construction and maintenance of compensating or regulating works is another matter which requires international action. Such works would affect lake levels within the boundaries of both countries. They have often been proposed to correct lake lowerings which were the result of several diversions, some in one country and some in the other. It appears desirable that such works should be constructed under joint supervision and paid for by an equitable international apportionment of the cost.

167. The same statements apply to the remedial works in the Horseshoe Rapids, which are described in Appendix C.

168. *Treaty provisions.*—Matters pertaining to the diversion of water from boundary waters between the United States and Canada are now controlled by a treaty ratified on May 5, 1910. The text of this treaty is quoted in full in Section I 2 of Appendix G. In the interest of clearness, and to avoid possible future complications, it is deemed advisable to modify Articles II and III of this treaty so as to extend the jurisdiction of the International Joint Commission to cover the diversion of water from streams and lakes tributary to boundary waters.

169. Article V of the treaty deals with the diversions of water from the Niagara River for power production. For reasons given in Appendix G, the considerations which caused the unequal division of water between the two countries, as provided in this article, are no longer operative. Under plans outlined in Appendices C and D a much greater diversion than that authorized in Article V can be allowed, while at the same time the scenic preservation will be cared for in the best possible manner. A new treaty should provide for the diversions stated in Appendix C, namely, each country to be allowed to divert 20,000 cubic feet per second around the Falls and Lower Rapids, and 20,000 cubic feet per second additional around the Falls alone. It would be well to provide also for the possibility that operation under this plan may show still greater diversions to be permissible.

170. A modification of the introductory sentence of Article V is also desirable. It now reads that the parties consider that "it is expedient to limit the diversion of waters from the Niagara River so that the level of Lake Erie and the flow of the stream shall not be appreciably affected." It is an historical fact that one of the chief reasons for the negotiation of this treaty was the desire to preserve

the scenic beauty of the Falls and rapids; therefore this reason might well be added to those given in the text quoted.

171. In the attempt to operate large hydroelectric plants very close to an authorized limit of diversion, occasional accidental peak loads may cause an unintentional overstepping of the limit. If these are not permitted the plant must habitually be operated at less than the allowed load, thus reducing the total output of power. For this reason it would seem that the treaty, and the permits issued under it, should not penalize such occasional accidental excess diversions.

172. It is believed that no modification of the treaty will be required in order to allow the construction of compensating works other than the "remedial works" in the Horseshoe Rapids. Such matters can be handled by joint legislative action in the two countries, and by the International Joint Commission.

173. *Interests of various States.*—Eight of our States and two provinces of the Dominion of Canada abut upon the waters of the Great Lakes and St. Lawrence River, and are affected by diversions of these waters. Six other States on the Mississippi River below the point where the diversion of the Chicago Drainage Canal is received have at least a theoretical interest in that diversion. These States and provinces have a total population of about 61,000,000 people, containing 53 per cent of the population of the continental United States and 63 per cent of the population of the Dominion of Canada.

174. The State of Missouri claimed a vital interest in the Chicago diversion on the ground that it endangered the health of residents of St. Louis and other places. When they sought relief by a suit in equity, the Supreme Court of the United States dismissed the suit "without prejudice" on the ground that the plaintiffs had failed to prove damage. It is not impossible that the case may some day be reopened.

175. The other States on the Mississippi have but a theoretical interest in the Chicago diversion. The aid which it affords to low-water navigation is very small above the mouth of the Missouri River and trifling below that point. The additional height of floods which it causes is of no practical importance.

176. The States abutting on the Great Lakes all suffer damage from the diversions made in two of them, namely, Illinois and New York. The nature and extent of this damage has already been discussed.

177. Such controversies as arise from these diversions, where a number of States are damaged by diversions which benefit another State appear to fall within the jurisdiction of the Federal Government. This view has not always been accepted, and the claim of Illinois that the diversion of water from the lake adjacent to its shores is a purely domestic matter with which neither the United States nor any single State can interfere, except in a damage suit, is now before a Federal court. It is hoped that a decision in this case (*United States of America v. The Sanitary District of Chicago*) will afford a permanent settlement of this question.

178. The State of New York has admitted the right of the United States to place a limit on the diversions of water from the Niagara River, but insists that the only right of the Federal Government is to fix a limit to the total diversion, and that it is within the province

of the State to allot this diversion to various power companies or utilize the diversion itself, and to regulate the manner in which it may be used.

The contrary view is that the Government may grant permits for certain parts of the diversion and may make such permits conditional upon the attainment of certain efficiencies, the maintaining of certain rates, or the observance of any other conditions it sees fit to impose. This latter view would appear to be more in accordance with the trend of recent legislation, and recent decisions of the Supreme Court.

179. *Rate control and regulation.*—The water power of the Niagara River constitutes a natural monopoly. The amount of power developable there will always be limited, and can always be sold profitably at a price much lower than the average cost of power throughout the country. Therefore there can never be any permanent condition of competition among the various companies developing Niagara power, and the natural operation of economic laws will not of itself keep the rates down to a reasonable figure. When new power houses are built a temporary situation may occur in which there is more power capacity than the existing market can absorb, and for a time vigorous, and even destructive, competition might exist, but such a condition could not continue. In a few years a market sufficient to use the total output of the power plants would be built up, and non-competitive conditions would return. The only survival of the period of competition would be such long-term contracts as might have been made for power at unprofitably low rates, and such excess charges to new customers as might be made in an attempt to make good the deficiencies.

180. It is apparent, therefore, that the privilege of developing the water power of the Niagara River will always constitute a monopoly. Whether that privilege be concentrated in the hands of a single company or divided among a number of independent concerns will have no effect upon its monopolistic character, nor will it make any permanent difference in the selling price of power, except that the lesser overhead costs of a single large company might enable such a concern to do a profitable business at a slightly lower rate.

181. It has become a well established principle in this country that the rates charged by a monopolistic or semi-monopolistic public service corporation ought to be controlled and regulated by some executive branch of the State or National Governments. This principle applies with full force to the corporations developing Niagara power. The proper basis for rate making by any regulating commission is usually expressed by saying that the company shall receive a "fair return upon the fair value" of its property.

182. *Recommended treaty provisions.*—It is recommended that the treaty with Great Britain proclaimed May 13, 1910, be modified in the following particulars:

(1) That the wording of the treaty be altered to extend the jurisdiction of the International Joint Commission to include diversions from tributaries of boundary waters except in the case of diversions from a tributary which are returned to the same tributary.

(2) That the words, "the scenic beauty of the Falls and rapids," be inserted in the first sentence of Article V after the word "Erie."

(3) That the diversion of water from Niagara River below the Falls be specifically limited in the same manner as the diversion from the Niagara River above the Falls.

(4) That the treaty provide for the construction and maintenance of remedial works of the nature outlined in Section E of this report; such works to be built under the supervision of the International Joint Commission, or of some other international body created for the purpose; the remedial works to be so designed and constructed that the scenic beauty of the Falls will be restored and preserved when 80,000 cubic feet of water per second is diverted from the Niagara River above the Falls; the expense of constructing and maintaining said works to be borne equally by the high contracting parties.

(5) That the limits of diversion from the Niagara River above the Falls which the high contracting parties may permit within their respective jurisdictions be raised from 20,000 cubic feet of water per second on the United States side to 40,000 cubic feet of water per second, and from 36,000 cubic feet of water per second on the Canadian side to 40,000 cubic feet of water per second.

(6) That 20,000 cubic feet per second of the water so diverted upon each side of the river shall be returned to the Niagara River at some point or points upstream from turning point number 134 of the international boundary line adopted August 15, 1913, by the International Waterways Commission under Article IV of the treaty between the United States of America and the United Kingdom of Great Britain and Ireland, signed April 11, 1908; and that if any part of the remaining diversion be returned to the Niagara River at any point an equal or smaller amount may be again diverted from any point farther down stream.

(7) That the limits given above be stipulated to apply to the amount actually diverted at any instant, and that accordingly the words "in the aggregate" and "daily" be stricken out of Article V of the present treaty wherever they occur; that it be recognized that small, brief, accidental violations of the provisions of a diversion permit must be allowed if the holder of the permit is to obtain the full value thereof, and that therefore such violations shall be permitted under such regulations as the International Joint Commission shall provide.

(8) That five years after the completion of the remedial works the International Joint Commission, or some other body constituted for the purpose, shall inform the high contracting parties whether or not, in its opinion, further diversions of water from the Niagara River for power development can be made, either continuously or intermittently, without serious injury to the scenic beauty of the Falls and rapids, the integrity of the river as a boundary stream, or appreciable lowering of lake levels. That, if this opinion be favorable to the further diversion of water, the commission or body shall indicate the amount of further diversion which may properly be allowed, and the conditions by which permits should be limited.

183. *Recommended use of diversions.*—In regard to the use of the various diversions of water from the Great Lakes and Niagara River, the following recommendations are made.

(1) That no change be made in the method of dealing with diversions whose primary use is for navigation purposes.

(2) That Federal control of the diversion at Chicago and in the vicinity be established by such measures as are necessary, provided the United States courts do not uphold the present apparent right of the Federal Government to regulate the diversions there; the Sanitary District of Chicago being permitted to divert from Lake Michigan and its tributaries a total quantity of water not exceeding at any time a flow of 10,000 cubic feet per second; under the conditions that the Secretary of War shall supervise the diversions as he deems best, that the expense of supervision shall be paid for promptly at stated intervals by the Sanitary District of Chicago, that no dangerous conditions shall be created in navigable waters, that the Sanitary District agrees to be responsible for any damage claims arising because of the diversion, that it shall pay its share as determined by the Secretary of War of the cost of such compensating works as the Federal Government considers necessary because of diversions of water from the Great Lakes system, that it agrees not to request or make any diversion in excess of that herein stated, that it shall pay to the United States for water used for power purposes at a rate per cubic foot to be based upon the relative value of the power as developed and that which could have been developed by its use at Niagara Falls, N. Y., and along the St. Lawrence River, and that it does all in its power to secure any State authority needed to enable it to undertake the establishment of provisions for sewage disposal other than by dilution and when so enabled provides as rapidly as necessary such sewage disposal facilities as are needed to care for the growth of the district.

(3) That consideration be withheld on all proposals for water diversions for combined navigation, power, and sanitary purposes, unless of far reaching importance and effects and consistent with plans approved by the International Joint Commission as remedial against the pollution of boundary waters.

(4) That the present method of controlling the power diversions at Sault Ste. Marie be not disturbed.

(5) That the total diversion through the Welland Canal for power development be limited strictly to the present amount.

(6) That the diversion through the New York State Barge Canal for power development be limited to the 500 cubic feet per second now allowed.

(7) That, as soon as a treaty has been negotiated with Great Britain along the lines indicated in section (k), additional permit or permits be granted so as to make the permitted diversion from Niagara River above the Falls on the United States side 40,000 cubic feet per second, one-half of which is returned to the river in the Maid-of-the-Mist pool.

(8) That the Secretary of War, the International Joint Commission, or a special board of engineers be requested to prepare plans and estimates in detail for a comprehensive system of compensating works for restoring the levels of all the lakes and their outflow rivers, these plans to be submitted to the International Joint Commission for approval, with the intent that such works be constructed, and paid for jointly by the United States and Canada.

184. It is fitting and proper to formally acknowledge the valuable services rendered in the conduct of this investigation and in the preparation of the report thereon by Mr. W. S. Richmond, Assistant En-

gineer, by First Lieut. Albert B. Jones, Engineers, United States Army, and by Maj. Robert S. Hardy, Engineers, United States Army. Mr. Richmond has devoted himself untiringly and loyally to the work from its beginning and to his ability and energy are due in large measure any merit in its results. Lieut. Jones has contributed to the work a high degree of skill and intelligence particularly in the elaborate computations on comparison of power projects and in his report on the preservation of the scenic beauty of Niagara Falls. Maj. Hardy, who was under my direction but a short time, and then in addition to other important duties, rendered valuable assistance.

185. Acknowledgment is made of the many courtesies extended by the officials of the Dominion of Canada and of the Province of Ontario in furnishing information and in extending facilities for visiting works under their control under war conditions.

186. Acknowledgment is also made to the officials of the department of public works of the State of New York and of the State engineer's office for important information.

187. Valuable cooperation and assistance was also rendered by the district engineers of the several engineer districts on the Great Lakes, particularly by Asst. Engineer F. G. Ray, in charge of the United States Lake Survey.

188. To the officials of the power companies at Niagara Falls, N. Y., and Canada, I am indebted for many courtesies and much valuable information.

189. Acknowledgment is also made for valuable suggestions from Hugh L. Cooper & Co., R. D. Johnson, consulting engineer, Allis-Chalmers Manufacturing Co. and I. P. Morris & Co.

J. G. WARREN,
Colonel, Corps of Engineers, United States Army.

APPENDIX A.

DESCRIPTION OF DIVERSIONS.

[Sections A, B, and C of Mr. Richmond's report.]

From: W. S. Richmond, assistant engineer.
 To: The Division Engineer, Lakes Division, Buffalo, N. Y.
 Subject: Transmitting report on investigation of water diversion from Great Lakes and Niagara River.

1. There is submitted herewith report on investigation of water diversion from Great Lakes and Niagara River.

2. It is divided into nine sections, as follows:

Section A: Diversions for navigation purposes.

Section B: Diversions for sanitary purposes.

Section C: Diversions for power purposes.

Section D: Field and office operations.

Section F: Propositions for utilizing diversions with greater economy.

Section G: Effects of diversions on lake levels.

Section H: Economic value of diversions.

Section I: International and interstate matters involved.

Section K: Recommendations.

Section L: Acknowledgments.

W. S. RICHMOND,
Assistant Engineer.

SCOPE OF REPORT.

This report treats of diversions of water from the Great Lakes, whether for navigation, sanitary, or power purposes. All diversions of sufficient magnitude to be considered worthy of mention have been included, a statement of the character, quantity, and effect of each being given as briefly as seemed consistent with clearness. Both present and proposed diversions are considered. Comparatively little is given of the voluminous historical, technical, and legal details involved, although the main points are presented. The major portion of the report is devoted to the Niagara diversions.

The territory involved in a comprehensive consideration of these diversions is the entire drainage area or basin of the Great Lakes above St. Regis, N. Y., 66 miles above Montreal, the place at which the St. Lawrence River passes entirely into Canada. This area is approximately 300,000 square miles, of which 59.5 per cent lies on the United States side of the international boundary line.

The total area is somewhat larger than that of Texas, and about $1\frac{1}{2}$ times the size of France. The land area on the United States side of the line is greater than the combined area of the New England States and New York State. It includes practically the whole of the State of Michigan and portions of Minnesota, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania, and New York. The land area on the Canadian side comprises a large part of the Province of Ontario. The population of the basin area is estimated to be 15,000,000, of which about 2,000,000 are in Canada. At least 16 cities of over 50,000 population are located within its boundaries. The water surface area alone is 95,205 square miles, and 60,975 square miles of this, or 64 per cent, is in the United States. The main shore line involved exceeds 8,300 miles in length. The total developable water power is estimated to be approximately 10,000,000 horsepower, far more than half of which is in the United States. The water power already developed within this area is roughly one million horsepower in the United States, and one and one-half million horsepower in Canada. The lake commerce in 1917 was carried in more than 1,000 vessels of an average registered tonnage exceeding 2,000 tons, about 90 per cent of the vessels having a registered tonnage of over 100 tons, while 41 vessels had a dead-weight tonnage of 13,000 tons or more. The maximum length of freight steamer was 625 feet, maximum beam 64.2 feet, and maximum draft used, 21.9 feet. The total freight passing through Detroit River during the navigation season of 1917 was 95,000,000 tons, valued at approximately \$1,250,000,000. There is a not inconsiderable lake commerce which does not pass through Detroit River. The length of steamer track from Montreal to Duluth is 1,340 miles, and from Montreal to Chicago it is 1,260 miles.

The drainage area under consideration is depicted on plate 1, on which are shown the outlines of the Great Lakes and connecting and outflow rivers, the outline of the entire basin of the Great Lakes above St. Regis, the outline of the drainage basin of each individual lake, the international boundary line through the lakes, and the general location of waterways through which water is diverted from the Great Lakes, or tributaries of the Great Lakes, together with other data of a general character.

Diversions of waters of the Great Lakes basin will first be treated under the three divisions of navigation, sanitation, and power development. Some diversions pertain to only one of these uses, some to two, and others to all three. Where they pertain to two or more uses they will be treated under each division concerned, the remarks in each case being confined in so far as practicable to the particular use under consideration. Each diversion will be described upon its first mention in the report.

SECTION A.

DIVERSIONS FOR NAVIGATION PURPOSES.

1. ST. MARYS FALLS CANAL.

The total diversion of water from St. Marys River for navigation purposes is about 1,000 cubic feet per second on the average for the entire year, the rate reaching approximately 1,400 cubic feet per sec-

ond as an average for the busiest month of the season of navigation. In 1887 the average annual rate of diversion was only 150, and the increase to date has been gradual. It is estimated that the fourth lock, to be opened in 1919, will require an annual average diversion of about 350 cubic feet per second. These figures include the diversions on both sides of the river. All these diversions are made at the head of the rapids, and are returned to the river within 2 miles of the points of diversion. In the following paragraphs the character of the diversions is explained more at length. There are other and much larger diversions at the same place for power development, and these are described in Section C of this report.

Description of St. Marys River.—St. Marys River forms the outlet of Lake Superior, connecting the eastern end of the lake with the northern end of Lake Huron by a somewhat circuitous route 66 miles long by the westerly channel, and 75 miles long by the easterly channel. Through this passage flow the surplus waters of Lake Superior, a volume averaging 75,000 cubic feet per second. The drop in water level from Superior to Huron averages 20.7 feet (over a period of years), 19.4 feet of this occurring in a rapids three-fourths of a mile long near the head of the river, abreast of the city of Sault Ste. Marie, Mich. The surface levels of the lakes vary constantly, causing variations in the volume of water discharged through the river and producing changes in the fall of water level from above to below the rapids. This local fall varies between the limits of 17 and 21 feet. The general outline of the river is shown on the map designated as plate 2.

Commerce at Sault Ste. Marie.—There is a large lake commerce between communities on Lake Superior and points on the lower lakes during those months of the year when the harbors and river channels are not choked with ice. The season of navigation on Lake Superior opens late in April and closes early in December. During the season of 1917 there were 22,885 vessel passages past Sault Ste. Marie, made by 1,182 vessels. The total freight carried was 89,813,898 tons, valued at \$1,196,922,183. The average freight rate was 0.121 cents per ton per mile. The type of lake vessel principally used is shown in photograph No. 1. Sometimes as many as 50 vessels are tied below St. Marys Rapids in a blockade as indicated in the photograph. This commerce follows the natural and improved waterways of the westerly channel of St. Marys River. At Sault Ste. Marie it passes around the rapids in artificial canals about 1 mile long. Locks are provided to overcome the difference in water level already described, there being several locks, so that a number of vessels may be accommodated at the same time, although each lock overcomes the entire fall in one lift. There are at present three locks on the United States side and one lock on the Canadian side of the river. A single canal serves the Canadian lock. On the American side there are two canals, the South canal serving both the Poe and Weitzel Locks, and the North canal now serving the third lock and designed also to serve the fourth lock now under construction. The arrangement of locks and canals is well shown on the map marked plate 3.

Locks and canals.—The first canal and lock at the "Soo" as the locality about St. Marys Rapids is known, were constructed in

1797 and 1798 on the Canadian side of the river by the Northwest Fur Co. The lock, shown in photograph No. 2, was 38 feet long, 8 feet 8 inches wide, with a lift of 9 feet. A towpath was made along the shores for oxen to track bateaux and canoes through the upper part of the rapids. The picture shows the lock as restored. It was destroyed by United States troops in 1814.

The first canal on the American side was built in 1853 to 1855, and was known as the State Canal. It was $1\frac{1}{2}$ miles long, 64 feet wide at the bottom, and 100 feet wide at the water surface. There were two tandem locks of masonry, each 350 feet long by 70 feet wide, with a lift of about 9 feet. The depth in the canal was about 13 feet and in the locks about $11\frac{1}{2}$ feet, at the stage of water then prevailing. The locks are shown in photograph No. 3. They were destroyed in 1888 by excavations for the present Poe Lock.

The Weitzel Lock, 515 feet long, 80 feet wide in chamber narrowing to 60 feet at the gates, with 17 feet depth of water on the miter sills, was built by the United States in the years 1870 to 1881. During the same period the canal was correspondingly deepened, and was widened to 160 feet at its widest part, narrowing at the International Bridge to 108 feet; and the stone slope walls were replaced with timber piers having a vertical face. Present depth on miter sills at low water is 13 feet.

The Canadian Canal is $1\frac{1}{2}$ miles long, 150 feet wide at the top and 142 feet at the bottom, and has a lock 900 feet long and 60 feet wide. It was built in the years 1888 to 1895. It was constructed with a depth of 23 feet in the canal and 22 feet on the miter sills at the mean stage prevailing at that time. At present stages the upper approach to the lock has a depth of $21\frac{1}{2}$ to 24 feet, the lower approach 19 to 20 feet, and the depth on miter sills is about 19 feet.

The Poe Lock, 800 feet long, 100 feet wide, and having 22 feet of water on the sills, was built by the United States in the years 1887 to 1896. Present low-water depth on the miter sills is 18 to 19 feet. The average depth on miter sills in 1917 was 20.3 feet.

The third lock is 1,350 feet long, 80 feet wide, and has $24\frac{1}{2}$ feet of water upon its miter sills at existing stages. It was built in the years 1908 to 1914, and was opened to traffic October 21, 1914.

The fourth lock, now under construction, is shown in photograph No. 4 as it appeared May 26, 1917. It is to be of the same dimensions as the third lock. It is now nearly completed.

Since 1892 the canal leading to the Weitzel and Poe Locks has been widened to 270 feet, except where the width is restricted by the pier of the International Bridge and the movable dam to two passages of 108 feet each, and deepened to 24 feet in its upper reach. Since 1908 the United States has built another canal, north of the first, leading to the new third lock, and designed to serve the fourth lock also. It is 310 feet wide above the locks, narrowing to 282 feet at the railway bridge, and widening to 300 feet at the upper end. Least depth of water is $24\frac{1}{2}$ feet.

Photograph No. 5 shows the Weitzel Lock before the building of the Poe Lock. Photograph No. 6 is a view of all three United States locks as they now exist. No. 7 is a view of the downstream end of the Canadian Lock.

Considerable dredging has been done in the St. Marys River downstream from the locks. The Lake George route was first improved, a channel with 12-foot draft being provided before 1869. By 1883 this had been increased to 16 feet. The route via Hay Lake and Mud Lake in the west channel was then improved until in 1894 a 20-foot depth had been provided. Betterment of channels has been continued since that time with a view to providing a 21-foot depth at lowest stage of water, and separating upbound from downbound traffic in certain reaches.

To date the United States has expended approximately \$24,000,000 on the construction of the locks, canals, and channels of St. Marys River. Cost of operating and repairing the locks and canals is about \$125,000 per annum. The Canadian Lock, canal, and approaches cost roundly \$5,000,000.

From 1855 to 1881 the American canal was controlled by the State of Michigan, and tolls were charged to cover operating and repair expenses, the rate at first being 6½ cents per registered ton, which was gradually reduced to 2½ cents. Similarly the minimum charge for lockage of a boat was reduced from \$5 to \$3. Since control was transferred to the United States in 1881, the American canal has been free for public use by all nations. Likewise at the Canadian canal no tolls have been collected for either foreign or domestic commerce.

The foregoing description has been given in order to make clear the character and importance of the diversions of water from St. Marys River for navigation purposes. These diversions comprise the water used in locking boats up and down, that used in operating gates and valves of the Poe and Weitzel Locks, and the leakage through the locks. This water passes around St. Marys Rapids in the three navigation canals above described. The Government owns a small hydroelectric power plant in the rapids. It is operated by the Edison Sault Electric Co., from whom power is purchased for operating the third lock and for lighting locks and approaches. The water diverted for this purpose will be considered, along with that used by other power plants at the Soo, later in this report under the heading of diversions for power development purposes.

Dredging the West Neebish Channel has caused a considerable change in distribution of flow between this channel and Middle Neebish, but this does not constitute a diversion of water from the river.

Diversions.—During the months of January, February, and March each year traffic is completely suspended because of ice, the lock gates are closed, and the locks pumped out and kept empty. During this time there is no diversion for navigation other than a slight leakage, which amounts to less than 100 cubic feet per second for all the locks.

During the operating season of 1917, April to December, both inclusive, the general average and highest monthly average uses of water for navigation purposes, in cubic feet per second, were as given in the following table, Table No. 8. The Weitzel Lock was not in operation in 1917. The average recorded use of water for navigation purposes during the season of navigation was 177 cubic feet per second in 1887, and it increased gradually to a maximum of 1,411 cubic feet per second in 1916. Considering the entire 12 months of

the year, the diversion of waters of St. Marys River for navigation uses is now roundly 1,000 cubic feet per second, having increased gradually to this amount from a diversion of only about 150 cubic feet per second in 1887. It is estimated that the fourth lock will require an average of 450 cubic feet per second during the navigation season and 25 cubic feet per second during the winter, or an average for the entire year of approximately 350.

TABLE No. 8.—*Approximate water diversion at locks, Sault Ste. Marie, 1917.*

Name of lock and use.	Cubic feet per second.	
	Average for season April-December.	Average for highest month (August).
Weitzel:		
Lockage.....	0	0
Operation.....	0	0
Leakage.....	39	39
Total.....	39	39
Poe:		
Lockage.....	290	393
Operation.....	8	10
Leakage.....	98	98
Total.....	396	501
Third:		
Lockage.....	339	467
Leakage.....	128	128
Total.....	467	595
Canadian:		
Lockage.....	141	191
Leakage.....	41	41
Total.....	182	232
All locks:		
Lockage.....	770	1,051
Operation.....	8	10
Leakage.....	306	306
Total.....	1,084	1,367

2. CHICAGO SANITARY CANAL AND ILLINOIS AND MICHIGAN CANAL.

For the past few years there has been no direct diversion of waters of the Great Lakes through the Illinois and Michigan Canal. A small part of the water diverted through the Chicago Drainage Canal enters the Illinois and Michigan Canal at Joliet. Formerly water was diverted directly from Lake Michigan through the Chicago River, entering the Illinois and Michigan Canal at Bridgeport. The amount thus diverted seldom exceeded 850 cubic feet per second. In addition there was a small diversion from the Calumet River, a tributary of Lake Michigan. Of this diversion it is believed no more than 300 cubic feet per second at the very most was required for navigation purposes.

The diversion through the Chicago Sanitary Canal averaged about 8,800 cubic feet per second in 1917, although daily averages ran as high as 10,000, and the discharge in the lower part of the canal

reached 17,500 cubic feet per second for a short time. The entire diversion was for sanitary purposes. As a secondary matter, however, this water was used to a considerable extent in the generation of power, an average flow of about 6,800 cubic feet per second being utilized for this purpose. It is estimated that 500 cubic feet per second would be ample to serve any navigation requirements of the present canal. Should the Des Plaines and Illinois Rivers be improved to accommodate navigation of 8-foot draft to the Mississippi, a diversion of 1,000 cubic feet per second might be required to meet the needs of navigation only.

Descriptions of the Illinois and Michigan Canal and the Chicago Sanitary Canal are given in the succeeding paragraphs of Section A of this report, together with statements concerning features pertaining mainly to navigation. The sanitary and power features are treated in Sections B and C, respectively.

The general location of the Illinois and Michigan Canal, the Chicago Sanitary Canal, and the Illinois River are shown on plate No. 1. The route of the canals above Joliet is more clearly shown on plate No. 4.

Description of Illinois route.—The surface of Lake Michigan is approximately 580 feet above the surface of the ocean. The city of Chicago, at the west side of the southerly end of Lake Michigan, is built on nearly level ground whose surface is generally 15 to 25 feet above the lake. Near the western edge of the city, 10 miles from the lake, is the Des Plaines River, paralleling the lake shore. At a point almost abreast of the center of the city the river turns and follows a southwesterly direction. At this point the surface of the Des Plaines is about 10 feet above the lake. A shallow, narrow valley or depression extends from this point eastward to the south branch of Chicago River, its bottom being 5 to 15 feet above the lake. Through this depression a part of the waters of Des Plaines River formerly flowed in times of freshet, and the early explorers were able at such times to navigate canoes and bateaux across the divide which normally separates the waters of the St. Lawrence and Mississippi Valleys. It is through this depression in the divide that the Chicago Sanitary and Ship Canal and the Illinois and Michigan Canal were constructed. A somewhat similar depression, about 10 miles farther south, extends from the Des Plaines River to the Calumet River. Along this route the Calumet-Sag Drainage Canal is now being constructed. The old Calumet feeder of the Illinois and Michigan Canal was constructed in this depression. The Calumet River discharges into Lake Michigan, as did the Chicago River before it was reversed and made to discharge into the sanitary and ship canal. Plate 5 gives a small map of the region around Chicago showing the features just enumerated.

The Des Plaines River joins the Kankakee River 15 miles below Joliet, forming the Illinois River, which is 273 miles long, and empties into the Mississippi River about 38 miles above St. Louis. The total fall in water surface from Lake Michigan to the Mississippi at the mouth of the Illinois River is about 165 feet. The United States has improved the river for navigation purposes from La Salle at the foot of the Illinois and Michigan Canal to Grafton, at the confluence of the Illinois and Mississippi. In this length of about 223

miles the fall is approximately 30 feet. The available draft at low water in the Illinois River between La Salle and Peoria is 6 feet, though not for the full projected width of 200 feet. Between Peoria and the Mississippi River there is an available depth of $5\frac{1}{2}$ feet, referred to level of low water of 1901, except at two bars, where shoaling has reduced the depth to 4 feet. There are four locks in the Illinois River between La Salle and the Mississippi, each 350 feet long and 75 feet wide, with 7 feet depth on the miter sills. At each lock the water surface of the upper level is held up by a dam, providing slack-water navigation. The first two locks below La Salle—one at Henry, 196 miles above the mouth of the river, and one at Copperas Creek, 137 miles above the mouth—are operated by the State of Illinois and tolls are collected. This charge is \$1.50 on boats of 150 tons and under, and on larger boats is 1 cent per ton-measurement. The other two locks—one at La Grange, 78 miles above the mouth, and one at Kampsville, 31 miles above the mouth—are operated by the United States and are free from tolls.

The Illinois and Mississippi Canal connects the Illinois River at a point $2\frac{3}{4}$ miles above Hennepin and 13 miles below La Salle with the Mississippi River at Rock Island. It does not use waters of the Great Lakes Basin.

The portion of the Des Plaines and Illinois Rivers between Joliet and La Salle has not been used to any extent for navigation since the pioneer days when this natural waterway formed the only practical route to the West and carried the primitive commerce of the times in canoes and bateaux. The fall from above the State dam at Joliet to La Salle is about 100 feet, the distance being 66 miles. At the State dam at Joliet there is a fall of about 11 feet. At Marseilles there is a private dam providing a fall of about 11 feet. There is no lock at the Marseilles dam. These dams and the power developments located at them will be described later in this report under the heading of "Diversions for power purposes."

On August 26, 1905, a board of engineers reported to the Chief of Engineers, United States Army, plans and estimates for a navigable waterway 14 feet deep from Lockport, Ill., by way of the Des Plaines and Illinois Rivers to the mouth of the Illinois River and thence by way of the Mississippi River to St. Louis, Mo. Plans and estimates were also presented for a 7-foot waterway and for an 8-foot waterway from Ottawa, Ill., down the Illinois River to La Salle, Ill. The 14-foot waterway was to have locks 600 feet long and 80 feet wide. Below La Salle the locks and dams were to be removed and the 14-foot depth maintained by a minimum discharge of 10,500 cubic feet per second. No opinion was expressed as to the advisability of undertaking any of these projects. The report is published as House Document No. 263, Fifty-ninth Congress, first session.

A report submitted by another Board of Engineers on August 15, 1913, published as House Document No. 762, Sixty-third Congress, second session, recommends the construction of a navigable waterway excavated 11 feet deep but calculated to serve vessels drawing 8 or 9 feet, extending from Lockport, Ill., by way of the Des Plaines and Illinois Rivers to the mouth of the Illinois, and thence by way of the Mississippi to St. Louis. The State of Illinois was to pay the cost of the waterway from Lockport to Utica, 7 miles above La Salle.

The remainder of the route was to be constructed at the expense of the United States and was estimated to cost \$1,050,000 for the portion in the Illinois River, with \$115,000 annually for maintenance; and \$3,710,000 for the portion in the Mississippi River, with \$125,000 annually for maintenance. The old locks below La Salle were to be altered slightly but maintained with their present horizontal dimensions of 75 by 350 feet. The channel was to be 160 feet wide in canal and 200 feet in open river. The board proposed that the new locks above La Salle should be 600 feet long, 80 feet wide, and with 11 feet of water on the miter sills, but was agreeable to the proposition that the State, in its cooperative efforts, should build them larger if it wished. The State proposed that the portion of the waterway which it was to build, namely, that above Utica, should have a wetted channel 300 feet wide and 24 feet deep from the Lockport power house for $5\frac{1}{2}$ miles to the Brandon Bridge, just below Joliet, and from there to Utica a channel 9 feet deep and 200 feet wide at bottom for the present, to be deepened to at least 14 feet later. It proposed the construction of five locks, the uppermost beside the Lockport power house at the downstream end of the Chicago Drainage Canal, the next at Brandon Bridge, and the last at Utica. Each lock was to be 80 by 900 feet in horizontal dimensions, with 24 feet of water on the miter sills. On November 3, 1908, the people of the State of Illinois voted for an amendment to the constitution permitting a bond issue of \$20,000,000 for the construction of such a waterway. Several years later \$5,000,000 of this was appropriated but no construction work was undertaken, because the necessary cooperative arrangement with the Federal Government was not effected. It was estimated that \$20,000,000 would provide for the excavating noted above for the lock at Lockport and for the four dams and power houses at the other lock sites, and possibly for the other four locks also.

The Board of Engineers considered a volume of flow of water of 1,000 cubic feet per second more than sufficient for such a waterway.

THE ILLINOIS AND MICHIGAN CANAL.

The Illinois and Michigan Canal extends from a point on the South Branch of the Chicago River in the city of Chicago southwesterly to La Salle, Ill., where it enters the Illinois River. Its length is 97 miles and its fall is 142 feet at low water stages of Lake Michigan and the Illinois River. Its point of beginning is $5\frac{1}{2}$ miles from Lake Michigan, measured along the Chicago River. From this point it passes westward across the low divide, through the natural depression in the land surface previously described, about 7 miles to the valley of the Des Plaines River. Following along the southeasterly side of the valley of this river, it enters the river in the city of Joliet 32 miles from its point of beginning. It proceeds but a short distance in the river channel, and then, at the State Dam, leaves the river on its northerly side, following the northwesterly rim of the valley of the Des Plaines River to the junction of the Des Plaines with the Illinois, and thence along the northerly side of the Illinois River to La Salle. Construction of the canal began in 1836 and was completed in 1848. The canal had a surface width of 60 feet, a bottom width of 36 feet in earth sections and 48 feet in rock, and a depth of

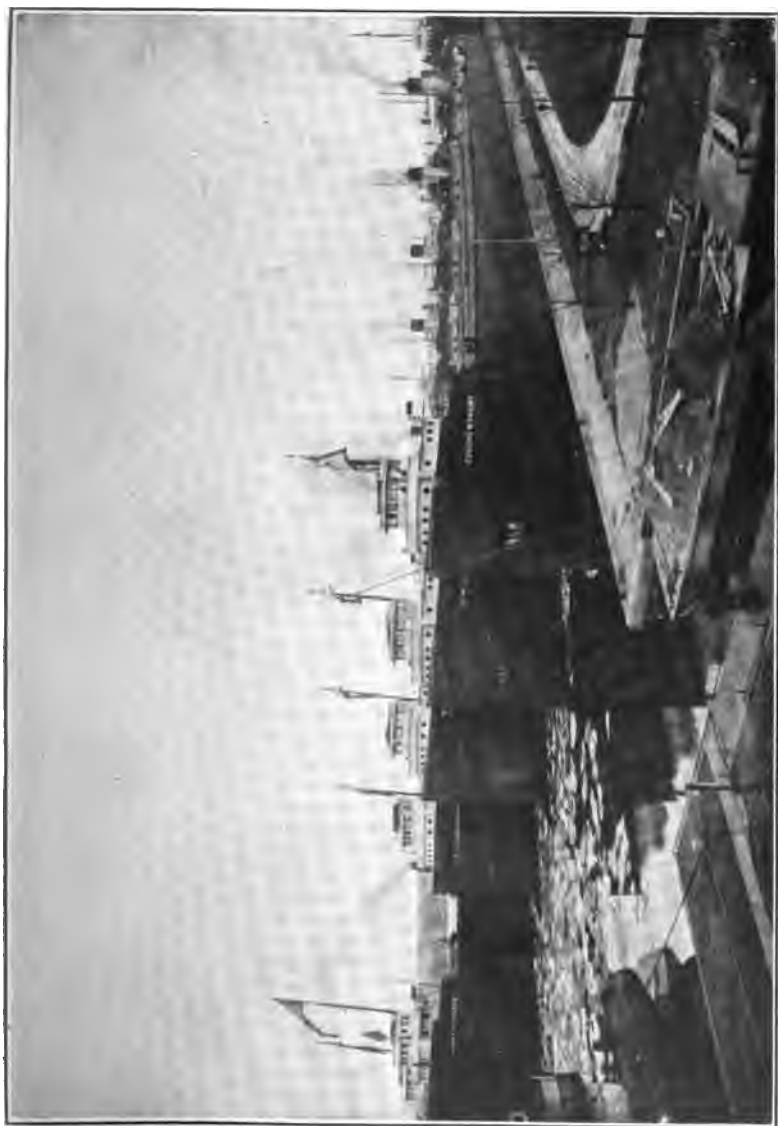
water of 6 feet. All bridges over the canal were fixed, the minimum clearance being about 11 feet. The locks were 110 feet long and 18 feet wide, having a depth of 6 feet of water on the sills. There were 15 lift locks and one guard lock.

As originally constructed there was at the head of the canal a summit level $26\frac{1}{2}$ miles long which was 8 feet above the level of Lake Michigan and was fed from the Des Plaines and Calumet Rivers, as well as by a lift wheel from the Chicago River. The water from Calumet River was conducted through the Sag Valley in a feeder canal $16\frac{1}{2}$ miles long. The summit level was cut down in 1866 to 1871. While the summit level existed it did not supply sufficient water to the reach of canal extending from Ottawa upstream toward Joliet. To make an adequate supply available the Kankakee feeder was constructed. This feeder canal received water from the Kankakee River at a point several miles above its junction with the Des Plaines, and conducted it to the Illinois and Michigan Canal at a point about 1 mile above the junction. The feeder water passed over the Des Plaines River in an aqueduct just before entering the canal. After the summit level had been cut down this feeder became unnecessary and was abandoned. The Fox River feeder received water from the Fox River several miles north of Ottawa, and conducted it to the canal at a point in Ottawa nearly a mile beyond the aqueduct which carries the Illinois and Michigan Canal over Fox River. This feeder also has been abandoned and some portions of it have been filled in. The total cost of building the canal, including cutting down the summit level, was \$9,513,000.

During the first 30 years of its operation the canal was much used and it earned a very substantial revenue. In 1879 the net receipts over expenses of operating up to that time were \$2,934,000. In addition to this, a total amount of \$5,886,000 had been received from the sale of canal lands. More than 300,000 acres of public land had been donated the State by the Federal Government as an aid in financing the canal and a large portion of this was sold. As late as 1902 there was a revenue from tolls of approximately \$30,000 a year. Now, the State receives very little from tolls, and has received very little since about 1905. There is a revenue from land rentals, ice privileges, and rental of water for power development, which, together with the receipts from tolls, enables keeping the canal open for navigation, but is inadequate to meet the expense of repairs or dredging to maintain a proper depth of channel.

There was some interruption of navigation in the vicinity of Joliet following 1905 due to operations of the Sanitary District of Chicago. The canal has fallen into disuse and poor repair. In 1916 it was navigated by a very few boats, mostly small pleasure craft. Its available draft had been reduced in places to $4\frac{1}{2}$ feet. In 1918 the Federal Government was dredging to restore this $4\frac{1}{2}$ -foot draft. The Illinois and Michigan Canal is a State project, and is under the State department of public works and buildings.

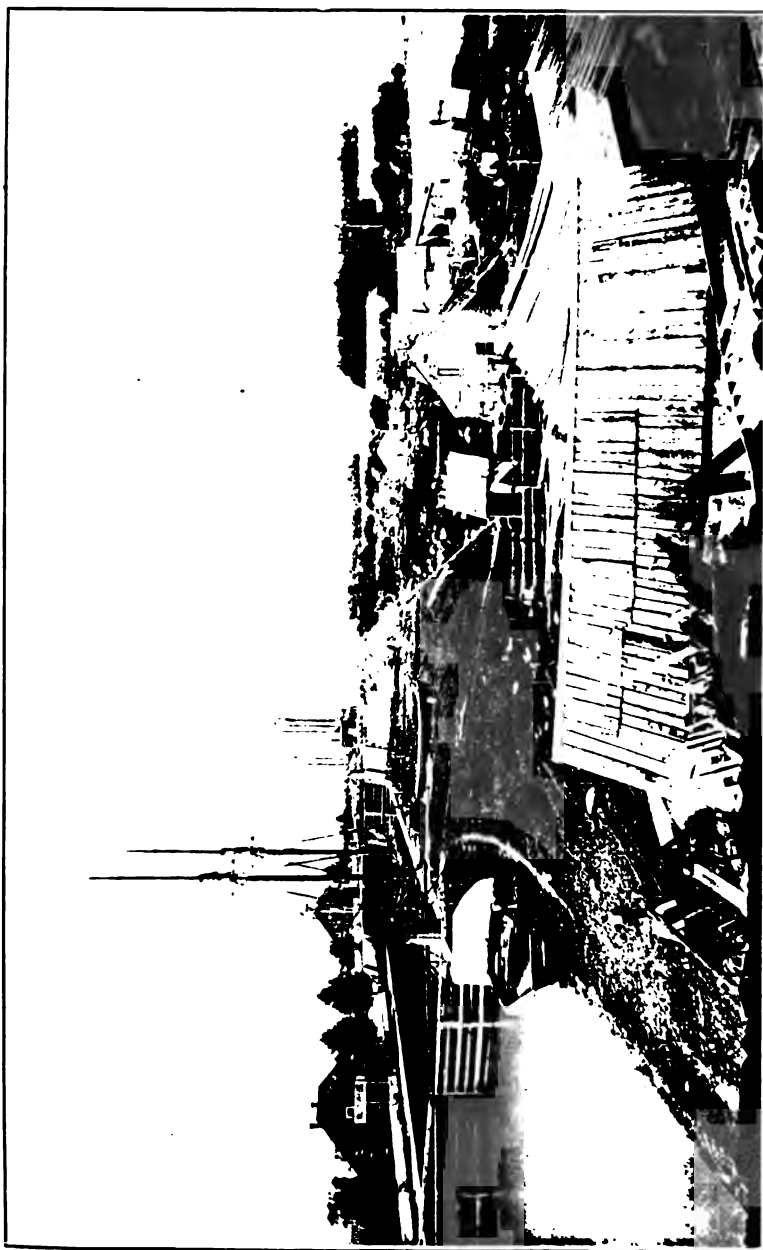
Diversion.—From the time of the opening of the Illinois and Michigan Canal in 1848 to the opening of the lock of the Main Drainage Canal on July 13, 1910, water was diverted from Lake Michigan through the Illinois and Michigan Canal into the Des Plaines River. The diversion was chiefly for sanitary purposes.



Photograph No. 1.—TYPICAL BULK FREIGHTERS OF THE GREAT LAKES.

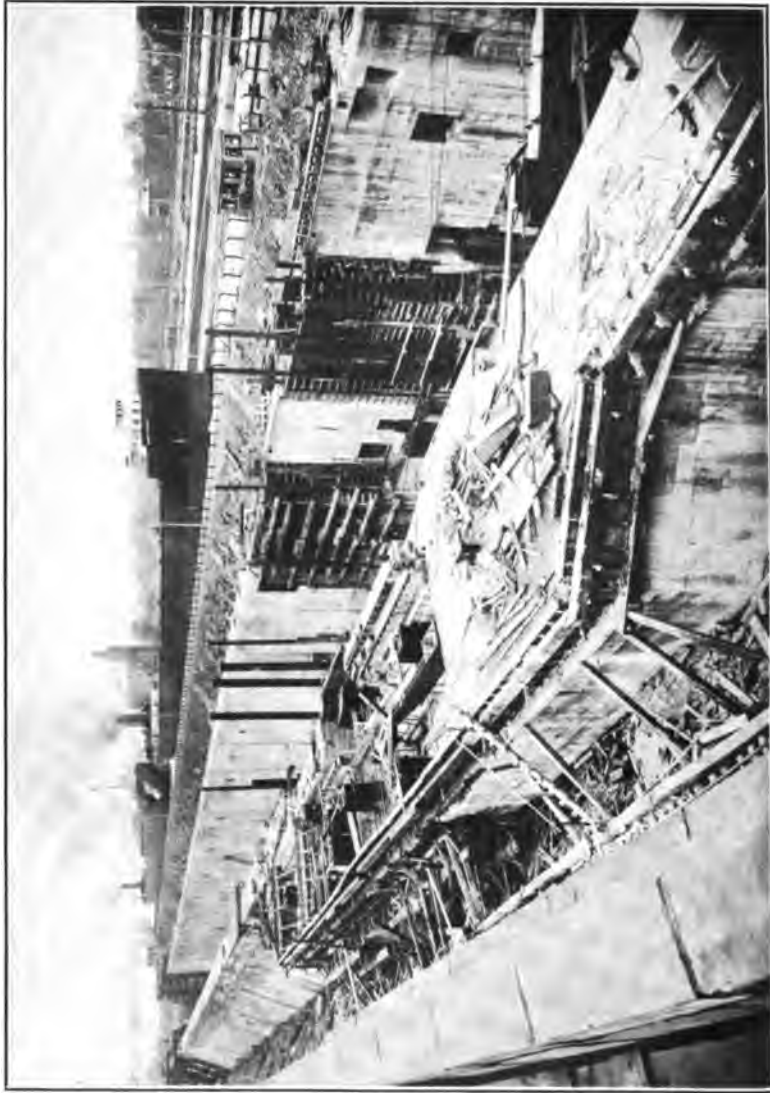


Photograph No. 2.—OLD LOCK AT SAULT STE. MARIE.
Built in 1797 by the Northwest Fur Co.



Photograph No. 3.—STATE LOCKS.

View looking West showing locks, Superintendent's dwelling, office, Indian huts, and Rapids. Probably taken in 1865.



Photograph No. 4.—FOURTH LOCK AT SAULT STE. MARIE (Under construction).



Photograph No. 5.—WEITZEL LOCK AT SAULT STE. MARIE.
Before construction of the Poe Lock.



Photograph No. 6.—WEITZEL, POE, AND THIRD LOCKS AT SAULT STE. MARIE.



Photograph No. 7. - CANADIAN LOCK AT SAULT STE. MARIE.



Photograph No. 8.—ILLINOIS AND MICHIGAN CANAL.



Photograph No. 9.—FOX RIVER AQUEDUCT, ILLINOIS AND MICHIGAN CANAL.



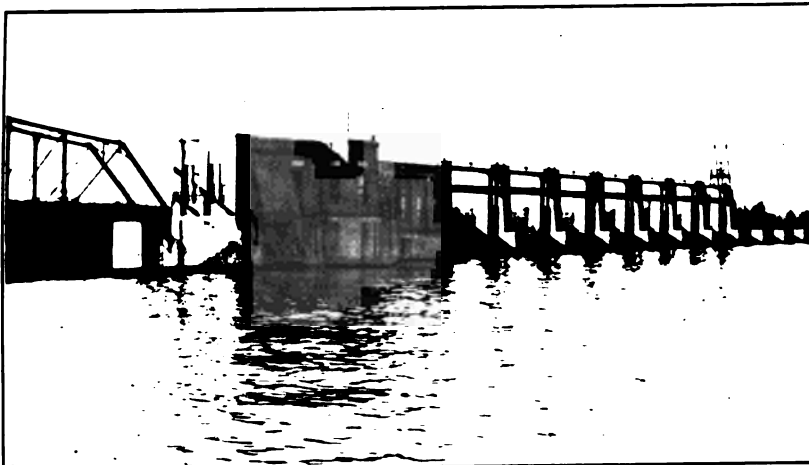
Photograph No. 10.—ANOTHER VIEW OF FOX RIVER AQUEDUCT, ILLINOIS AND MICHIGAN CANAL.



Photograph No. 11.—LOCK NO. 2, ILLINOIS AND MICHIGAN CANAL. (Abandoned.)



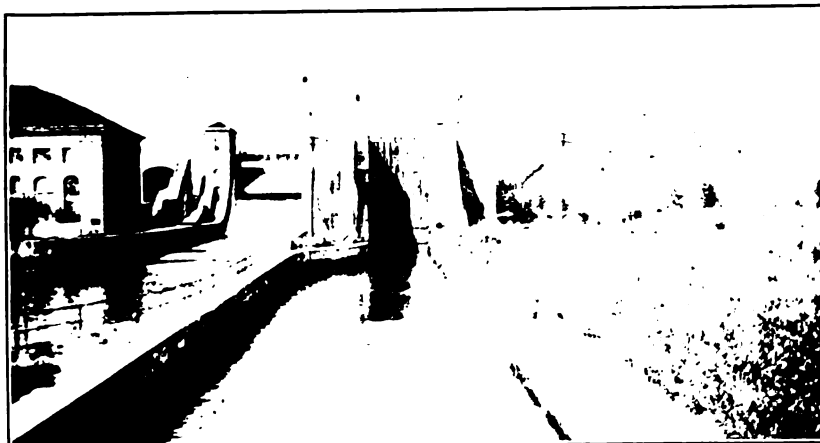
Photograph No. 12.—ROCK SECTION, MAIN DRAINAGE CANAL.



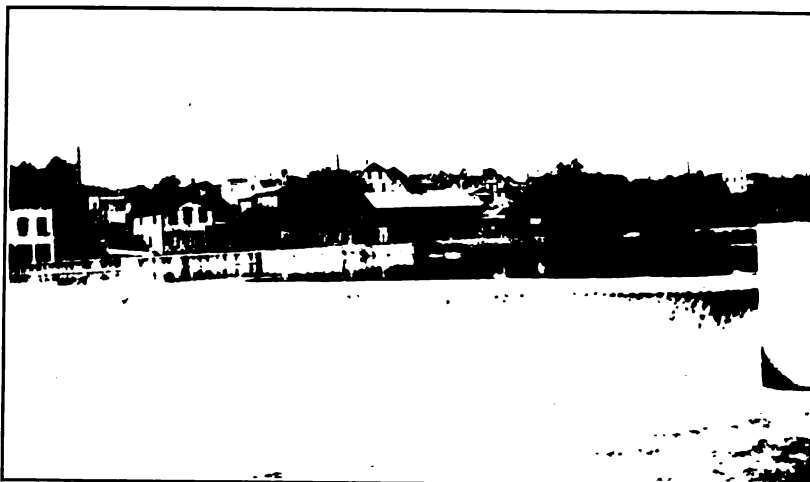
Photograph No. 13.—CONTROLLING WORKS, CHICAGO DRAINAGE CANAL.



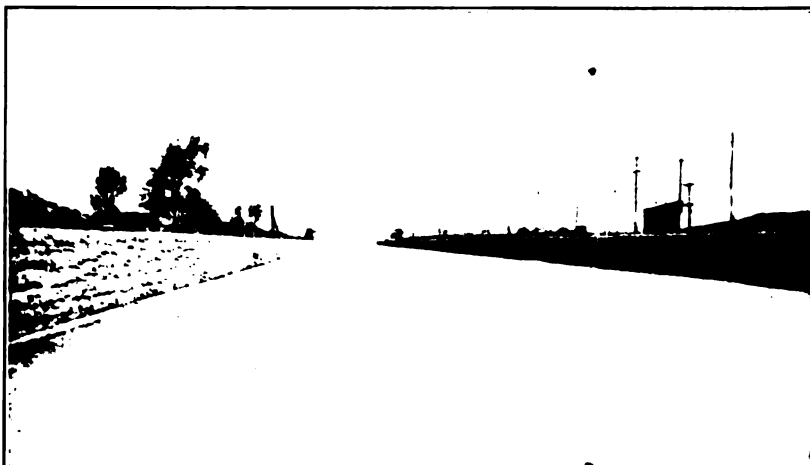
Photograph No. 14.—BEAR TRAP DAM, CHICAGO DRAINAGE CANAL.



Photograph No. 15.—DRUM DAMS AND LOCK, CHICAGO DRAINAGE CANAL.



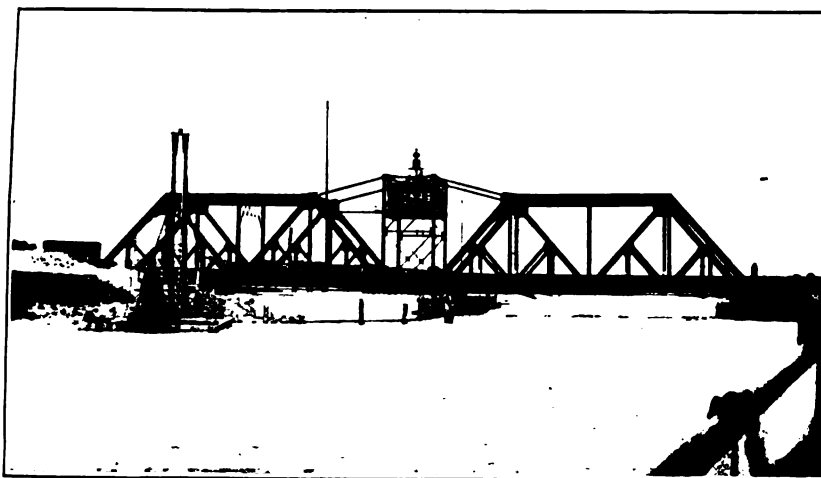
Photograph No. 16.—STATE DAM NO. 1, DESPLAINES RIVER.



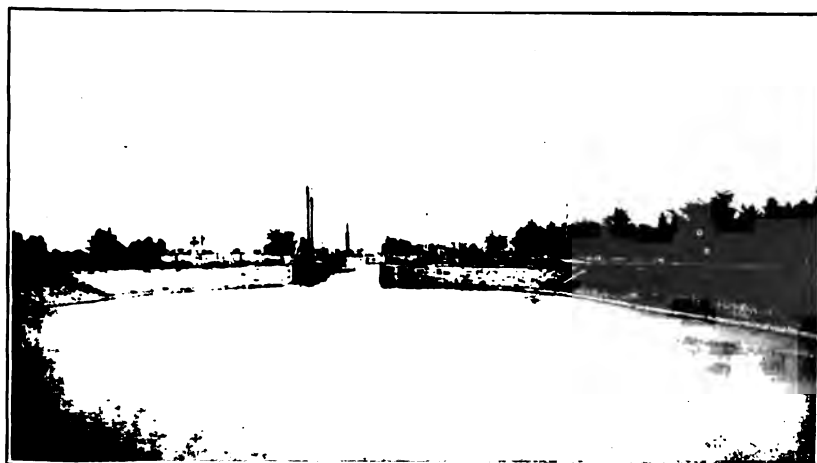
Photograph No. 17.—ROCK SECTION, PRESENT WELLAND CANAL.



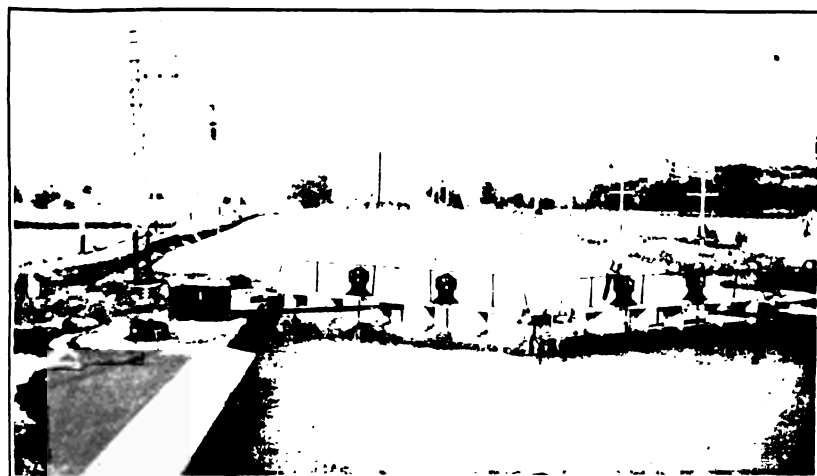
Photograph No. 18.—EARTH CUT, PRESENT, WELLAND CANAL.



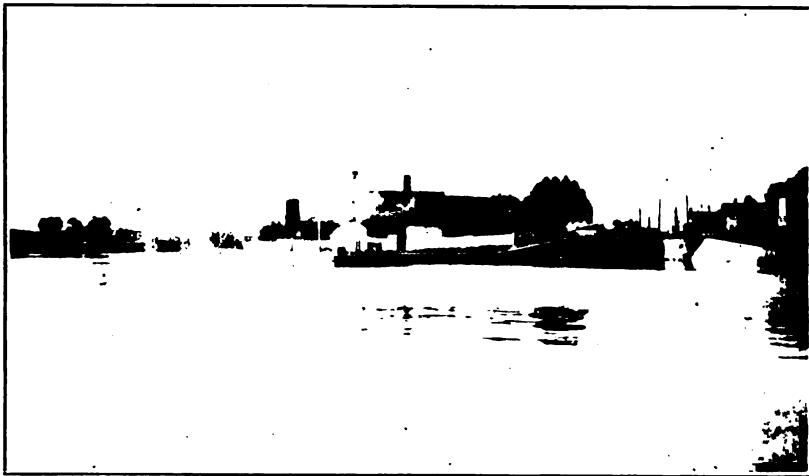
Photograph No. 19.—M. C. R. R. DRAWBRIDGE, PRESENT WELLAND CANAL.



Photograph No. 20.—GUARD GATES AND LOCK NO. 25, PRESENT WELLAND CANAL.



Photograph No. 21.—SERIES OF LOCKS, PRESENT WELLAND CANAL.



Photograph No. 22.—PORT DALHOUSIE, ONT.
Lock No. 1, Present Welland Canal, on left. Lock No. 1, Old Welland Canal, on right.



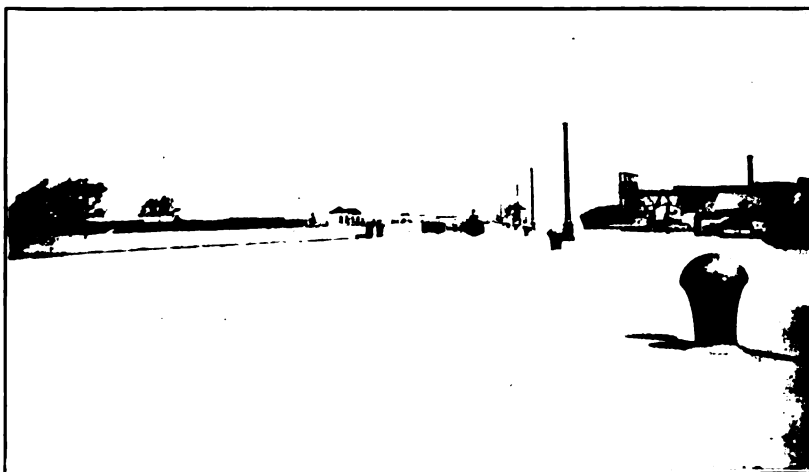
Photograph No. 23.—SLUICES ADMITTING WATER TO OLD WELLAND CANAL.



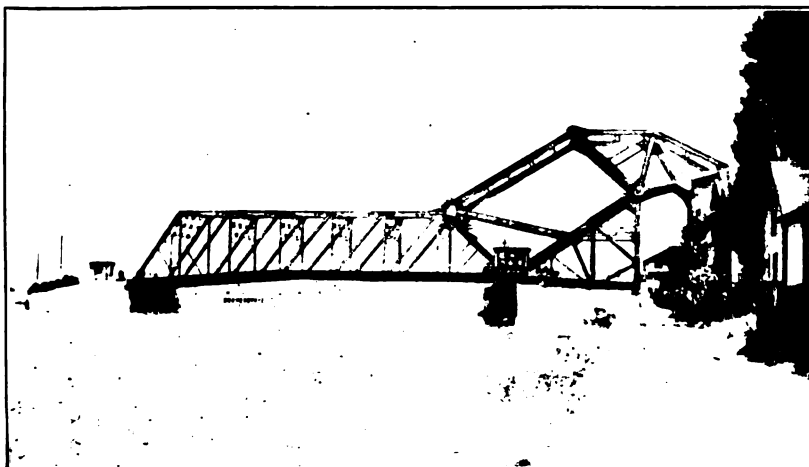
Photograph No. 24.—LOCK AND VIADUCT, OLD WELLAND CANAL.



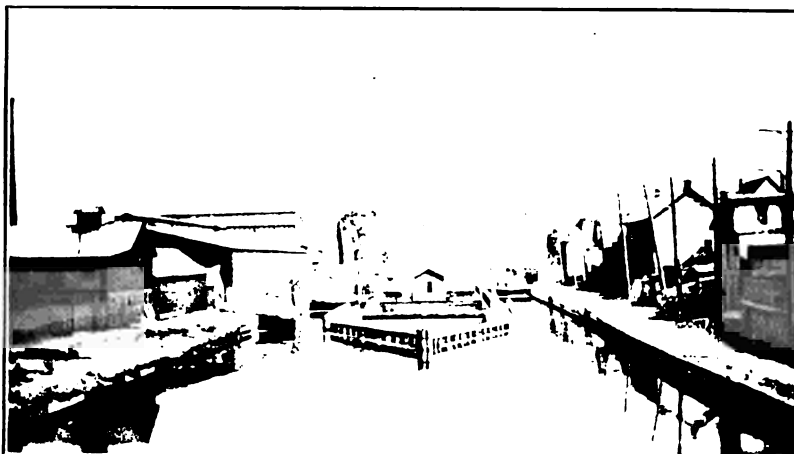
Photograph No. 25.—JUNCTION OF TWELVE-MILE CREEK AND OLD WELLAND CANAL.



Photograph No. 26.—BLACK ROCK SHIP LOCK.



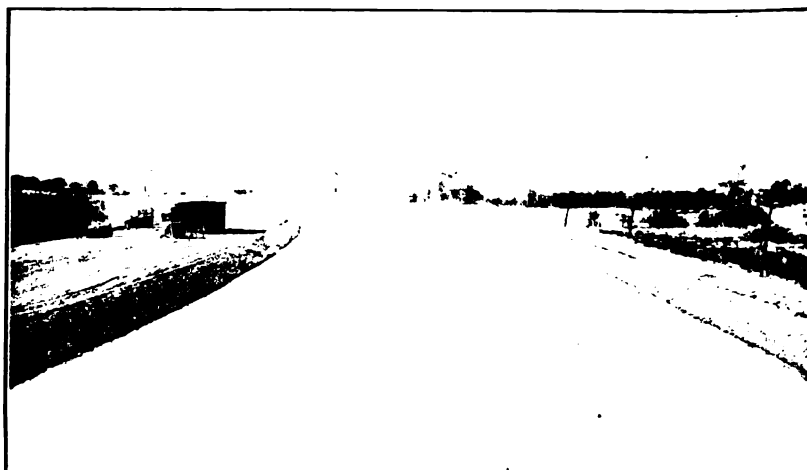
Photograph No. 27.—BLACK ROCK CANAL, FERRY STREET BRIDGE



Photograph No. 28.—GUARD LOCK NO. 72, OLD ERIE CANAL, BLACK ROCK, N. Y.



Photograph No. 29. —NEW YORK STATE BARGE CANAL.
Typical rock section under construction.



Photograph No. 30.—NEW YORK STATE BARGE CANAL.
Typical earth section.

however. The quantity required for navigation is not known, but it was undoubtedly less than 300 cubic feet per second. This was abstracted from Lake Michigan or withheld from the lake by being abstracted from its tributaries—the Chicago and Calumet Rivers. The canal has discharged as much as 2,100 cubic feet per second at Joliet in the spring when 362 cubic feet per second was being pumped in from the Chicago River. In order to cause a large flow through the canal it was necessary to close the gates at Chicago and pump water into the canal from Chicago River, raising the water surface in the canal several feet above the river level. A head of 5.7 feet was found to be required for a discharge of 1,000 cubic feet per second. Pumps accepted by the city of Chicago in 1886 had a capacity of 1,000 cubic feet per second, but the volume pumped seldom exceeded 850 cubic feet per second, and this was largely for sanitary purposes. Since completion of the Main Drainage Canal and Lock the portion of the Illinois and Michigan Canal above Joliet has been abandoned, and there is no diversion of lake water through it. Some short stretches of the canal near Chicago have been filled in by garbage contractors. The flow in this canal below Joliet comes from the Des Plaines River, whose small natural flow is greatly augmented by the large discharge from the Chicago Main Drainage Canal which empties into Des Plaines River just above Joliet. The average discharge of the Des Plaines River is roughly 400 cubic feet per second, but low-water discharges as small as 7 cubic feet per second have been measured and flood discharge as large as 11,900 cubic feet per second. The present discharge of the Illinois and Michigan Canal just below Joliet varies between 300 and 550 cubic feet per second. This is used up largely by leakage, seepage, evaporation, and power development, and is used only very slightly for locking boats. It is evident from the figures given above that normally only a portion of this water is furnished by the natural flow of the Des Plaines River, the rest coming from Lake Michigan by diversion through the drainage canal.

The present general appearance of the canal is shown in photograph No. 8. An upstream view of the aqueduct carrying the canal waterway over Fox River is given in No. 9, and a top view of the same in No. 10. A photograph of Lock No. 2 between Joliet and Lockport on the abandoned portion of the canal is given as No. 11. In this last picture it may be noted that there is a very small amount of drainage flowing through this lock.

Traffic.—The yearly average tons of freight transported on the canal from 1860 to 1916 was 544,629. The maximum tonnage for one year was carried in 1882 and was 1,011,287. The tonnage carried decreased materially from 1895, when railroads were most active in competition.

Tolls have always been charged. The rate on coal is 1 mill per ton per mile, on lumber 5 mills per 1,000 board feet per mile, and on merchandise 2 mills per ton per mile. In addition there is a toll on each boat of 3 cents per mile.

It is reported by the State superintendent of the division of waterways, under the department of public works and buildings, that there is a widespread demand for improvement of this canal,

and that a company has been formed and financed to construct boats for operation on it as soon as the required depth is available. The canal traverses a populous territory and has many industries that can utilize it located along it.

Canal lands.—An interesting point to note is that the act of Congress approved March 2, 1827, granting certain lands to the State in aid of building this canal provided that the lands were subject to the disposal of the State legislature "for the purpose aforesaid and no other," and that "said canal, when completed, shall be and forever remain a public highway for the purpose of the Government of the United States." The Department of Justice has held that the State should maintain the canal to fulfill its part of the contract, or return the consideration to the United States.

CHICAGO SANITARY CANAL.

The general location of the Chicago sanitary and ship canal is shown on plates 1, 4, and 5.

Description.—The Chicago sanitary and ship canal parallels the Illinois and Michigan canal from a point on the west fork of the south branch of Chicago River to the canal basin in Des Plaines River above Joliet, a distance of 32.35 miles. As projected the depth of water was to be 24.3 feet, the canal prism in rock was to be 160 feet wide at the bottom and 162 feet wide at the top, while in earth the prism was to be 202 feet wide on the bottom and 300 feet at the water surface, with side slopes of 2 to 1 under water and $1\frac{1}{2}$ to 1 above. As actually constructed the dimensions are as follows: From Robey street in Chicago to Summit, 7.8 miles, 162 feet wide at bottom and 226 feet at water line; Summit to Willow Springs, 5.3 miles, 202 feet wide at bottom and 290 feet at water line; Willow Springs to the controlling works at Lockport, 14.95 miles, 160 feet wide at bottom and 162 feet at water line. At the controlling works there is a fan-shaped basin with an extreme width of 502 feet. From these works to the lock at the power plant between Lockport and Joliet, 2 miles, the channel is of irregular width, nowhere less than 160 feet. The reach from Robey street to Summit was excavated wholly in earth. Originally only the south side of the canal was excavated, the bottom width being 110 feet. In 1912 to 1914 it was widened on the north side to the dimensions given above. From Summit to Willow Springs the excavation was mostly in earth, but there was some rock in the bottom of the prism. From Willow Springs to Lemont the excavation below water line was largely in rock. From Lemont to the end of the canal the excavation was almost entirely in rock. The depth of water in the canal upstream from the power house is 22 to 26 feet. The lock is 130 feet long and 22 feet wide, with 12 feet of water over the sills. Its average lift is 36 feet. From the lock to the Illinois and Michigan canal basin at Joliet, 2.3 miles, through rock, the canal has a minimum depth of water of 10 feet, bottom width of 160 feet and top width of 162 feet. It is planned by the sanitary district to build a larger lock when it is needed, unless the 80 by 900 foot lock planned by the State of Illinois and described previously is constructed.

The entrance of the canal at Robey Street is 6 miles from Lake Michigan, measured along the Chicago River. Originally the Chi-

ago River was a sluggish stream, nearly stagnant during the greater part of the year, but having a rapid current in rainy seasons. At times it discharged not only the run-off from its own watershed, but a quantity of water from the Des Plaines River, which passed over the low divide between the two streams. Between Robey Street and the lake the Chicago River now has a least depth of 21 feet in mid-channel and to within 20 feet of docks, except for the short distance between Robey Street and Ashland Avenue, where the least depth is 20 feet. The Sanitary District of Chicago, owner of the canal, aims to secure a depth of 26 feet for the midstream width of 100 feet, shoaling to 16 feet at the docks, with a clear river width of 200 feet between dock lines.

The controlling works are at Lockport, Ill., on the northwest side of the canal. They comprise a bear-trap dam 160 feet wide with a vertical play of 17 feet, and seven sluice gates of the Stoney type, each 30 feet wide and having a vertical play of 20 feet. These works provide a very efficient means of controlling the flow of water through the canal. To a limited extent the canal discharge may be controlled at the power plant, where, besides the lock, there are two drum dams, one 12 feet long and one 48 feet long, each having a vertical play of 18 feet. The narrower one is nearer the power house and is designed for use as an ice run. A butterfly dam is located just below the controlling works at Lockport, furnishing means for closing off the portion of canal leading to the lock and power house. It is a swing bridge affair with center pivot located on a pier in midstream. There is a channel 80 feet wide on each side of the center pier.

There are 18 bridges across the canal. Two of these are fixed and allow a free passage 40 feet wide with 18 feet of headroom above the water surface. The other bridges are either swing or bascule movable bridges, but 12 of these can not be opened because the operating machinery has never been installed, although the State law required that they should be operative by January 17, 1909. The least headroom under the inoperative movable bridges is about 16½ feet. There are two bridges at Lockport with a clearance above the water of only 4.8 feet, but these are in commission.

The Sanitary District began dredging in the Chicago River in 1896. Excavation of the Main Drainage Canal was commenced on "Shovel Day," September 3, 1892. The canal was first opened for the passage of water on January 17, 1900. The cost of the Main Drainage Canal, Chicago River improvement, and other items providing a navigable waterway from Lake Michigan to Joliet has been approximately \$50,000,000. This figure does not include the items required for sanitary or power development purposes, but in no way necessary for navigation. The annual cost of maintenance of the Main Drainage Canal is roughly \$75,000.

Traffic.—The use of the canal for navigation is very small. In 1917 there were 160 boats locked through at the power house. The largest boat passing the lock was 75 feet long by 14 feet beam, and the average size was about 40 feet by 8 feet. In addition there is a traffic on the canal hauling stone from Lockport to Chicago.

No tolls are charged against vessels navigating the canal or passing the lock.

Diversion.—It has never been necessary to estimate the diversion of water from Lake Michigan which would be required to operate the drainage canal as a navigable waterway, provided no sewage or water for sewage dilution or water for power development purposes were discharged into it, but it seems probable that 500 cubic feet per second would suffice amply. If the Des Plaines and Illinois River route for 8-foot navigation is developed, 1,000 cubic feet per second may be required from Lake Michigan.

Illustrations.—Photograph No. 12 is of the rock section of the Main Drainage Canal. Photograph No. 13 shows a portion of the controlling works, including the seven Stoney gates, one end of the bear-trap dam, the control house for one end of the dam, and a portion of the bridge spanning the dam. At the controlling works there are eight bays without gates, similar to the seven bays which have Stoney gates. Originally it was thought that gates might be installed in these bays later, but this plan has been abandoned. No. 14 is a picture of the bear-trap dam. No. 15 shows the drum dams, the downstream end and lower gates of the present lock, and a portion of the power house. No. 16 is a view of State Dam No. 1 at Joliet. The entrance to the Illinois and Michigan Canal is on the far side of the river.

3. WELLAND CANAL.

The diversion of water from Lake Erie through the Welland Canal appears to have been approximately as follows: During the season of navigation of 1917, 4,600 cubic feet per second; during the following closed season, 4,300; during the navigation season of 1918, 4,400; during the closed season, 4,100. In addition there was a supply of about 40 cubic feet per second from the Grand River, a tributary of Lake Erie. These figures are averages, and so, of course, the diversion has at times exceeded these amounts. Of these diversions 1,100 cubic feet per second was used for navigation, including lockage, leakage, and waste, during the open season, and 800 cubic feet per second during the closed season. Of the remainder a very small amount was used for sanitary purposes and the balance for power development. The diversion from the Grand River was begun in 1833. The diversion direct from Lake Erie was begun in 1881.

In the succeeding paragraphs there is given a general description and brief history of the canal, with special reference to the navigation features. The power features are treated in section C.

Description.—The Welland Canal connects Lake Erie with Lake Ontario. It is in Canada $5\frac{1}{2}$ miles west of Niagara River at the point where the distance is least, and runs approximately north from Port Colborne, 19 miles west of Buffalo on the north shore of Lake Erie, to Port Dalhousie on the south shore of Lake Ontario, 11 miles west of the mouth of the Niagara River. The route is shown on plate No. 6. The mean stage of Lake Erie for the years 1860 to 1917, both inclusive was 572.53 feet above mean sea level, on United States standard datum; while for the same years the mean stage of Lake Ontario was 246.18 feet; making the average drop for those years from upper to lower lake surface 326.35 feet.

The present Welland Canal, which is $26\frac{1}{2}$ miles long, overcomes this difference in elevation by means of 25 lift locks and one guard

lock. The locks are 270 feet long, 45 feet wide, and have 14 feet depth of water on the miter sills. Maximum available length for boats is 255 feet. The average lift is 13 feet, the maximum lift at any lock being about 18 feet. The lock valves are in the gates and are operated by hand. The gates themselves are operated electrically. The guard lock is at Port Colborne, one-half mile from the entrance to the canal. From there the canal extends 17 miles at Lake Erie level, except for the slight drop necessary to create a flow of water toward Lake Ontario, to the guard gates just above Lock No. 25. The distance along the canal from the guard gates to Lock No. 1 at Port Dalhousie is $9\frac{1}{4}$ miles. There are no locks in flight, and the levels between locks are in all cases at least long enough and wide enough to permit boats to pass. The depth in the upper level is controlled by the elevation of Lake Erie. At low stages of the lake the depth on the sill of the guard lock at Port Colborne, No. 26, is less than 13 feet, and at extreme low stage this depth has been as small as $10\frac{1}{4}$ feet. The canal prism was excavated in earth except for a short rock cut just north of Port Colborne, shallow rock cuttings south of the guard gates, and shallow to heavy rock cuttings at the lock sites. Bottom width is 100 feet, the side slopes being 1 on 2. At the city of Welland, 8 miles from Lake Erie, the canal is carried over the Welland River on a concrete viaduct.

History.—A brief history of the present Welland Canal and its predecessors is as follows: The construction of the first Welland Canal was begun in 1824 by a private corporation. In May, 1833, the canal was opened from Port Colborne to Port Dalhousie for navigation. The depth was $7\frac{1}{2}$ feet, the bottom width of prism being 26 feet in earth and 15 feet in rock. There was a long summit level 8 feet above the level of Lake Erie, fed from the Grand River by a feeder canal 21 miles long, which ran in a northeasterly direction from Dunnville on the Grand River to Welland on the canal. In 1841 the Canadian Government purchased the canal rights and in 1842 began an enlargement which was completed in 1850. As enlarged the canal prism was $8\frac{1}{2}$ feet deep and 26 feet wide on the bottom, and the feeder was increased to the same size. Subsequent to 1854, by the addition of copings the navigable depth of the canal, but not of the feeder, was increased to 10 feet. In 1872 the Government determined on a scheme for the general enlargement of the canal, the adoption of the Lake Erie level, and the obtaining of a water supply from Lake Erie at Port Colborne, in addition to the limited supply coming through the feeder from Grand River. This canal was an enlargement of the old canal from Port Colborne to Allanburg, about 15 miles, but from there to Port Dalhousie followed an entirely new route somewhat east of the old line. In 1882 this improved canal was opened for 12-foot navigation. When the aqueduct at Welland was completed in 1887 this canal, now known as the present Welland Canal, was made available for 14-foot navigation. The portion of the old canal from Allanburg to Port Dalhousie has been retained and is open to navigation but has been used only a very few times in many years. It is three-fourths mile longer than the line which replaced it and has 26 locks, each 45 feet wide and with $10\frac{1}{4}$ feet of water on the sills. Two of the locks are 200 feet long and 24 are 150 feet long. The old canal is used for water-power

new Welland Canals are shown more in detail, as well as their relation to Niagara River. Photographs Nos. 17 to 22, inclusive, are illustrative of the present Welland Canal, while photographs Nos. 22 to 25, inclusive, are illustrative of the old Welland Canal. Explanations are given beneath the pictures.

4. BLACK ROCK CANAL.

Water from Lake Erie is diverted around the head of Niagara River through the Black Rock Canal for a distance of about 4 miles. At the lower end of the canal some of the water passes into the head of the old Erie Canal. The rest passes through Black Rock Lock out into Niagara River. There is a small leakage from the Black Rock Canal into Niagara River along the upper portions of Bird Island Pier. The amount of this leakage was estimated to be about 250 cubic feet per second. From the lock records the requirement for lockage and waste at Black Rock Lock is approximately 50 cubic feet per second. In addition to these two quantities there is diverted down the Black Rock Canal whatever water flows in the Erie Canal at Black Rock. This quantity has been as great as 1,000 cubic feet per second. Since the removal of the dam at Tonawanda in the early spring of 1918 and the construction of the temporary dam across the old Erie Canal at Tonawanda, the flow into the upper end of the Erie Canal at Black Rock has been small, about 400 cubic feet per second. This has been spilled into Niagara River at Tonawanda, except for what was lost by seepage and evaporation. The Erie Canal as improved to form the barge canal now receives its western water supply from Niagara River at Tonawanda.

Following is a brief description of the canal and lock of the Black Rock Canal, with statements regarding the navigation features. The old power developments are referred to briefly in Section C.

Description.—The general relation of the Black Rock Canal to Niagara River is shown on plate No. 6. The canal and lock are shown better on plate No. 7.

The Niagara River breaks out from Lake Erie over a ledge of limestone abreast of the city of Buffalo, N. Y. Not far from the lake the stream is only 1,600 feet wide at its narrowest place. In this cross section it has a maximum depth of 15 feet at mean stage and a velocity approximating 8 miles per hour. The fall from Horse-shoe Reef Light, at the head of the river, to the foot of Squaw Island, $3\frac{1}{4}$ miles, is approximately 5.1 feet, varying somewhat with the stage of Lake Erie. From Squaw Island the river slope is comparatively gentle, for about 15 miles by the shortest route, to the head of the rapids above the Falls.

To aid navigation in passing this swift shallow portion of the river a channel, known as the Black Rock Canal, has been constructed along the eastern edge of the river from Buffalo Harbor to the foot of Squaw Island. The upper end of Black Rock Channel is at the foot of Maryland Street, about a mile from the north or main entrance to Buffalo Harbor. The channel which has been dredged from the main entrance of the harbor to the canal is 21 feet deep, and is 400 feet wide from the southerly end of the north breakwater to the northerly end of the State breakwater, abreast the foot of Georgia Street, and 500 feet wide from there to the head of the canal. On ac-

count of shoaling at the Lake entrance, the present available depth is about 18 feet. The canal itself is formed by a breakwater largely of rock, known as Bird Island Pier, extending from a point opposite the foot of Maryland Street to the head of Squaw Island, about $2\frac{1}{2}$ miles, and by the passage between Squaw Island and the main shore. Within this space, which is $3\frac{1}{2}$ miles long, and varies from 220 to 1,400 feet in width, is a dredged channel 21 feet deep and 200 feet wide extending for $3\frac{1}{2}$ miles from the head of Bird Island Pier to the lock near the foot of Squaw Island. This channel is 240 feet wide on curves, and is only 150 feet wide at the Ferry Street and International bridges. These are the only bridges crossing the canal and they have clear openings of 150 feet in each case, the bridge at Ferry Street being of the bascule type and the International Bridge of the swing type. The clear headroom under these bridges when closed, at mean stage, is 15 feet. The canal water surface is at Lake Erie elevation at its upper end, and has only a very slight drop to the lock.

The Black Rock Lock, connecting the canal with the Niagara River near the foot of Squaw Island, is 650 feet long between hollow quoins and 70 feet wide, has a usable length of 625 feet, usable width of 68 feet, depth of 22 feet on the miter sills at low stage, and average lift of about 5 feet. It is electrically operated and lighted.

The river portion of Bird Island Pier, extending from the head of Squaw Island up to Bird Island, was constructed by the State between 1823 and 1825 in connection with the building of the Erie Canal. At this time the dike between Squaw Island and the main shore was built also. These structures, in fact, formed a part of the Erie Canal. Between 1829 and 1834 the United States Government extended and repaired the upstream end of Bird Island Pier, and between 1869 and 1872 extended the pier from Bird Island to a point opposite the foot of Hudson Street. In 1891 and 1892 the pier was extended 900 feet to a point opposite the foot of Maryland Street. About 1825, mills were established on the dike between Squaw Island and the mainland, to develop water power provided by the 5-foot head of water held up by the dike. Water for power development was used in such quantities by these mills as to create a current very detrimental to canal navigation. To remedy this condition the State constructed an intermediate wall between Bird Island Pier and the main shore, some time between 1854 and 1867, providing a separate channel 70 feet wide for the Erie Canal, adjacent to the mainland. It was found that the water passing down this 70-foot channel to supply the navigation needs of the Erie Canal created too great a current, and accordingly, after 1871, the middle wall was moved out for the greater part of its length and the main bank was cut back sufficiently to provide a channel for the Erie Canal 150 feet wide. This division wall was never quite completed at its downstream end.

Black Rock Lock.—Some time previous to 1840 a ship lock was built between Squaw Island and the mainland. It was of timber, and soon decayed and leaked badly. In 1841 a new stone lock was commenced, but its construction was greatly delayed by financial difficulties of the State, and was not completed until 1851. This lock, which was sometimes called the "sloop" lock, was in operation until 1913, when it was removed, between July and November, to make room for the new approach channel to the present lock. The

old lock was 200 feet long, 36 feet wide, and had about 9½ feet of water on the sills at mean lake stage.

Construction of the present lock was commenced in 1907 and completed in 1913. The deepening and widening of the channel and building of Ferry Street Bridge were not finished until 1914. The present canal was opened to navigation August 17, 1914.

Cost and traffic.—The cost of this waterway to the State of New York is not known. The expenditures upon it by the United States from 1826 to June 30, 1918, for new work total \$3,945,563, including \$1,001,578 for the present lock. The United States spent very little for maintenance of it until the opening of the new lock and channel in 1914, and the maintenance cost to the State is not known. The expense of operation and maintenance has been borne by the United States since the opening in 1914, and has amounted to \$52,726.

The maximum number of vessel passages through the new lock was in the fiscal year ending June 30, 1916, and was 9,829. The number of vessel passages in the fiscal year ending June 30, 1918, was 6,304. Between 40 and 50 per cent of these passages were by motor boats or craft other than registered vessels. In the fiscal year ending June 30, 1918, the freight carried through the lock amounted to 1,632,846 tons, and this was the maximum carried in any fiscal year since the opening of the improved waterway. The value of this freight was \$8,579,217.

Diversion.—The amount of water diverted around the rapids at the head of Niagara River has never been known accurately. Statements made by the chief engineer and canal commissioners of the Erie Canal at the time Bird Island Pier was about to be constructed indicate that the natural discharge of the river through the area shut off by this pier was far greater than the flow ever obtaining down Black Rock Harbor and the Erie Canal. In recent years the discharge of the Erie Canal just below where it leaves the Black Rock Canal has been as high as 1,000 cubic feet per second. This flow was supplied from Lake Erie through the Black Rock Canal, in addition to the small requirements for lockage at the Black Rock Sloop Lock, and whatever water leaked out at the lock and through Bird Island Pier. At the present time the portion of the Erie Canal between Buffalo and Tonawanda is not in use, the water level being held up by a temporary dam at Tonawanda. The flow required is only that necessary to compensate for leakage, seepage, and evaporation in this reach of the old canal. In addition to this, however, there is spilled into Niagara River at the old spillway at Tonawanda about 400 cubic feet per second. The new Black Rock Channel must carry this water and also enough more to provide for lockage at the new lock, leakage through Bird Island Pier, and evaporation. It is estimated that the leakage is approximately 250 cubic feet per second and the lockage and waste at the lock less on the average than 50 cubic feet per second. Altogether it seems probable that the quantity of water diverted from Lake Erie is about 700 cubic feet per second, 300 of which is returned to Niagara River within a distance of 3¼ miles.

Three photographs are presented illustrating this waterway. No. 26 shows the new lock as it appears to-day. The other two, Nos. 27 and 28, are recent views of the canal. Brief descriptions are given beneath the pictures.

5. NEW YORK STATE BARGE CANAL.

The western portion of the New York State Barge Canal was opened in midsummer of 1918. There is no record of the quantity of water which has been diverted into it from Niagara River, but it is believed to have been less than the average amount assumed to be required ultimately, namely, 1,237 cubic feet per second. The maximum capacity of the canal to Lockport depends on the stage of Lake Erie and on the depth maintained on the upper sill of the first lock. It varies roughly from 1,000 to 3,000 cubic feet per second. East of Lockport the maximum discharge capacity of the canal is 1,600 cubic feet per second. For navigation use it seems likely that a diversion of 1,000 to 1,500 cubic feet per second will be required. A portion of the water thus required may also be used in the development of power at Lockport without interfering with navigation.

During the period of construction of the western part of the barge canal, from 1910 to 1918, the diversion averaged somewhat less than previously. At times there was no flow in the canal at all and the prism east of Pendleton was empty. Previous to 1910, for several years, the diversion which then came from Lake Erie by way of the Black Rock and Erie Canals ranged approximately between 500 and 1,000 cubic feet per second. Something like half of this amount was used for power development only.

These diversions from Lake Erie and Niagara River are discharged into Lake Ontario at Oswego and at various points between Niagara River and Irondequoit Bay, except for the portions lost by seepage and evaporation.

In addition a considerable drainage naturally tributary to Lake Ontario is diverted into the barge canal from Macedon to the Rome Summit level. Except for the losses by seepage and evaporation this finds its way into Lake Ontario at Oswego. There is also an average of about 50 cubic feet per second from the Mohawk Valley and 35 cubic feet per second from the Susquehanna River drainage basin diverted into this portion of the canal, and thus discharged into the Great Lakes system at Oswego.

The general location of the New York State Barge Canal is shown on plate No. 1. On plate No. 8 the portion of the canal mainly under discussion is shown more in detail.

A description and brief history of the canal with special reference to its navigation features is given in the following paragraphs. In Part C of this report is a short treatment of the power development along the canal.

Description.—The present New York State Barge Canal system provides a waterway of 12 feet minimum depth and not less than 94 feet width, except at locks, from Buffalo on Lake Erie, to the Hudson River at Waterford, and thence on down the Hudson past Troy and Albany to New York City. The Champlain branch from Waterford to Lake Champlain is of like dimensions, as are also the short lateral branches at Rochester and Syracuse, the Oswego branch, connecting the main canal with Lake Ontario at Oswego, and the Cayuga and Seneca Canal connecting the main canal with Cayuga and Seneca Lakes. The main or Erie branch proper, which is the improved Erie Canal, has its western end in the Niagara River at the mouth of Tonawanda Creek, at Tonawanda, N. Y., and its eastern

end in the Hudson River at Waterford. The distance between these two points, as measured along the center line of the canal, is 338.4 miles. From Tonawanda the barge canal route continues up the Niagara River and passes through the Black Rock Ship Lock and Channel 12.4 miles to a State terminal at Buffalo.

From Waterford the route follows down the Hudson River 2.3 miles to the lock and dam at Troy, at the head of tidewater, and then continues 7.7 miles farther to Albany, and thence on down to New York City. It is 353.1 miles from Buffalo to Troy via the canal, and 153 miles from Troy to the Battery in New York City, or 506.1 from Buffalo to New York by the route of the barge canal. The Champlain Canal is 60.7 miles long, the Cayuga and Seneca Canal 27.2 miles long, and the Oswego Canal 23.4 miles long. Altogether the barge canal system, counting the lakes, but not Erie and Ontario, provides 790 miles of navigation of barge canal dimensions. In addition there are portions of the older canals still available for use, as will be noted later.

Leaving the Niagara River at Tonawanda the barge canal follows a northeasterly direction about 18 miles to Lockport. There it turns and follows a generally easterly direction, approximately parallel with and 10 miles south of the shore of Lake Ontario, for 60 miles to the Genesee River. Continuing easterly its route reaches the head of Oswego River approximately 90 miles from the Genesee, as measured along the canal. Thence the route extends on eastward, passing through the 20 miles of length of Oneida Lake, to the Rome Summit level, and on down along the Mohawk River to Albany. It is 37 miles along the canal route from the head of Oswego River to Lock No. 21, at the westerly end of the Rome Summit level. This level is 18.22 miles long.

From Tonawanda to Pendleton, 9.58 miles, the canal is in Tonawanda Creek, except for three cut-offs at sharp bends. In the first 12,000 feet of this reach the water surface width approximates 200 feet, and the depth is 12 feet, at a stage of 565.50, barge canal datum, which is 564.37 on United States Standard datum, adjustment of 1903, elevation referring to the junction point of Tonawanda Creek and Niagara River. For the remainder of the distance to Pendleton the cross section closely approximates the standard barge canal section in earth, which is a trapezoid 12 feet deep with 75 feet bottom width and wide slopes of 1 on 2, making the width of water surface 123 feet. The banks are carried to a minimum height of 2½ feet above the assumed water surface, or 14½ feet above the bed of the canal. At Pendleton the canal leaves Tonawanda Creek and follows a land line from there to a point considerably beyond the Genesee River. From Pendleton three-quarters of the way to Lockport the section is almost entirely standard earth section. The remaining length is in rock cut with a standard section 94 feet wide on bottom, and having vertically channeled sides with 6-inch offsets at the top of each 9-foot lift. The bed of the canal has been given a slope toward Lockport, which increases toward Lockport, and makes the total drop from Tonawanda to Lockport 1.47 feet.

There are two new standard locks in flight at Lockport, providing for a total drop of 49.16 feet, from highest to lowest sill. These locks are Nos. 34 and 35, and they carry the canal down over what

is known as the Niagara escarpment. The next lift lock, No. 33, is $3\frac{1}{2}$ miles west of Pittsford, 64 miles from Lock No. 34, and 4 miles east of the Genesee River.

The reach of canal between Locks Nos. 33 and 34 is known as the "long level," or "sixty-mile level." As a matter of fact, it has been constructed with a sloping grade, the elevation of the canal bottom being 502.87 feet at Lockport and 500.60 feet at Genesee River, barge canal datum, giving a fall of 2.27 feet in 60 miles. With the exception of the three cut-offs on Tonawanda Creek previously mentioned and a short cut-off just west of South Greece, the new barge canal follows the line of the old Erie Canal from Tonawanda to South Greece, a few miles west of Rochester, where it takes a more southerly route and passes around the main portion of the city of Rochester, uniting with the old canal line again at Pittsford. The old Erie Canal has been deepened and widened to form the new barge canal, which for a considerable portion of its length is confined between artificial earth embankments. The canal is constructed throughout for a low-water depth of 12 feet. The artificial earth banks rise $2\frac{1}{2}$ feet above this assumed water level. The canal crosses the Genesee River at grade. This river rises in Pennsylvania and flows in a direction somewhat east of north across the State of New York into Lake Ontario at a point 77 miles east of Niagara River, as measured along the lake shore. The point at which the barge canal crosses the Genesee is 11 miles south of the lake and 3 miles south of the center of the city of Rochester. The old Erie Canal passes through the center of the city and is carried over the river on an aqueduct. The river itself is to be made navigable from the new canal crossing 2.9 miles northward into the heart of the city, the river surface being raised and regulated by means of a movable dam situated at the downstream end of this reach. At the crossing the water surface of the Genesee naturally fluctuates between the extreme low and high stages of approximately 507.7 feet and 522 feet, respectively, barge canal datum. To obtain 12-foot depth in the canal the stage at the crossing must be 512.6 feet. This is 4.9 feet above natural low stage. The required minimum stage of 512.6 feet will be maintained as closely as possible by manipulation of the movable dam. Guard locks are provided in the canal, one on each side of the Genesee a short distance from the river, and these are to be closed to protect the canal and its banks when high flood stages carry the river level more than a foot or two above regulated low stage.

From the Genesee River to the head of Oswego River, about 90 miles, there are 10 locks with lifts varying from 6 to 25 feet. The descent is continuous from Niagara River to Three River Point, at the head of the Oswego River, the fall being from 565.5 to 363 feet, barge canal datum, a drop of 202.5 feet. From the Genesee eastward to Macedon the canal is mainly a land line. From Macedon to Lyons it is partly a land line and partly a canalization of Ganarqua Creek. At Lyons the Ganarqua enters the Clyde River, and the canal follows the canalized Clyde, except at sharp bends, to Montezuma, where the Clyde enters the Seneca River, the outlet of Seneca and Cayuga Lakes. From Montezuma to Three River Point the Seneca River has been deepened and widened, and rectified at bends where necessary, to form the canal. At Three River Point the Seneca River from the west and the Oneida River from the east

unite to form the Oswego River. From this point the canal route ascends to the Rome Summit level, which is at elevation 420 feet, the total ascent being 57 feet. Leaving Three River Point the canal follows up Oneida River to Oneida Lake, passing through one lock, No. 23, which has a lift of 6.9 feet. East of Oneida Lake there are two locks, Nos. 21 and 22, with a combined lift of 50.1 feet. The canal follows the valley of Wood Creek to the city of Rome. Wood Creek passes through the western part of the city of Rome and flows westward while the Mohawk River passes through the eastern part and flows eastward. At Rome these streams are scarcely half a mile apart, although the former is a tributary of the Great Lakes, while the latter is a tributary of the Hudson River. Continuing eastward from the Rome Summit level the barge canal follows the Mohawk to Waterford, descending 404.8 feet from elevation 420 to elevation 15.2, in the pool above Troy Dam, by 19 locks whose lifts vary from 8 to 40.5 feet. The Mohawk has been canalized for the greater portion of this distance. In general, the channel has been excavated for a width of 200 feet in the rivers and lakes. A large number of fixed and movable dams have been required to provide slack-water navigation in the Clyde, Seneca, Oneida, and Mohawk Rivers. The portions of the barge canal east of the Rome Summit level are of little interest in this report, being outside the drainage basin of the Great Lakes.

Locks.—The locks of the barge canal are of standard design, having a width of 45 feet, a usable length of 311 feet, and a minimum depth of 12 feet on the miter sills. They are constructed of concrete and are built in line with one side of the canal prism. There are 34 lift locks and 2 guard locks on the Erie branch of the barge canal, not including the lock at Troy. The lock gates are all of the bivalve mitering type with the exception of the downstream gate of Lock No. 17, at Little Falls, and the gates of the two guard locks at Genesee River, which are of the lift type. Lock No. 17 has the highest lift of any barge canal lock, namely, 40.5 feet. The distance between gates of the lift locks varies with conditions from 338 to 343 feet. All lock gates and valves, and also the towing capstans situated on the lock walls, are operated electrically. The electric energy employed for these purposes and for lighting the locks is generated at the locks, except in the case of the Genesee River guard locks, where the power is purchased from the Rochester Railway & Light Co. There are small hydroelectric power stations along the Erie branch of the barge canal, within the territory embraced in this investigation, at Locks Nos. 34, 33, 29, 28B, 28A, 27, 24, 23, 21, and 20. Power is transmitted from No. 34 to No. 35, from No. 33 to No. 32, from No. 29 to No. 30, and from No. 21 to No. 22. There are gasoline-driven electric generating units at Locks Nos. 25 and 26, where the available head of water is only 6 feet. In almost every case there are two generating units at each power station, each unit having a 50-kilowatt, 250-volt, direct-current generator.

At Lockport, previous to the recent reconstruction of the Erie Canal to form the present Erie branch of the barge canal, there were five twin-locks in flight; that is 10 locks in a block 2 locks wide and 5 locks long. Each lock was 110 by 18 feet, inside horizontal dimensions, with 7 feet of water on the sills. The total lift was 57 feet.

The south flight of locks has been removed to make room for the two new standard-size locks, which are in flight, and overcome the entire lift. By a lowering of the upper level the lift has been reduced several feet, the reduction depending upon the stage of Lake Erie, and being nominally from 57 feet to 49.16 feet. There is no other place on the Erie branch of the barge canal where the locks are in flight without intervening basins, and only one other place on the barge canal system, namely, at Seneca Falls, on the Cayuga and Seneca branch, where there are two standard locks in flight. As in the case of Lockport, this flight overcomes a difference in elevation of 49 feet.

Wasteways.—There are numerous spillways and waste gates along the barge canal to facilitate regulating the water level at the desired elevation and to aid in preventing washouts of the banks. On the long level between Lockport and Rochester there are 13 spillways where water may be wasted into small natural water courses flowing northward into Lake Ontario. These small streams all pass under the canal in culverts, except at Medina, where an aqueduct carries the canal over Oak Orchard Creek. Each spillway consists of a waste weir 25 to 170 feet long, having its crest along one side of the canal, 12 feet above canal bed, and of two or more sluice gates. Each waste weir is designed for the use of flashboards to provide for deepening the canal in localities where it may be desirable and it is considered safe to use flashboards 1 foot high. Such use would permit the canal water surface to rise within $1\frac{1}{2}$ feet of the tops of the artificial earth embankments, which is as close as prudence admits, when consideration is given to the wash and surges caused by wind and passing boats and to a reasonable provision for safety against washouts.

Guard gates and bridges.—There are a good many guard gates along the barge canal, to provide for shutting off the flow of water in case of accident to locks, canal banks, aqueducts or bridges. These gates are all of the lift type, and are constructed in two parts with a central pier separating them, so that each gate shuts off half the canal prism. The gates nearest to Niagara River are at Pendleton, where the canal leaves Tonawanda Creek. On the long level, guard gates are located so as to divide the canal into lengths of 4 to 12 miles each. The number of bridges crossing the canal runs into the hundreds. Some of these are lift bridges, local conditions having required that they should be close to the water surface. Most of the bridges are fixed, however, the required minimum of clearance above canal water surface being $15\frac{1}{2}$ feet. There are no swing or bascule bridges, and the lift bridges are arranged to be raised at both ends and remain horizontal, spanning the canal whether raised or lowered, but providing the required clearance when in raised position.

Branch canals.—Cayuga and Seneca Lakes are located in the central western part of the State of New York, south of the Erie branch of the barge canal. They are long narrow lakes running nearly parallel in a north and south direction, at an average distance apart of about 12 miles. They are deep except at the ends. By doing a small amount of dredging at the shallow ends, and connecting the northern ends to the Erie branch through a fairly short canal, called the Cayuga and Seneca branch, they have been made a part of

the new barge canal system. Seneca Lake has its water surface at elevation 445 feet. It is $34\frac{1}{2}$ miles long and is 3 miles wide in the place of greatest width. The canal is $12\frac{1}{2}$ miles long from the northeast corner of the lake to its junction with the branch from Cayuga Lake, just north of the latter lake, and follows a direct line somewhat north of east. It drops 14.5 feet by a lock at Waterford and 49 feet by two locks in flight at Seneca Falls, reaching elevation 381.5 feet at the junction. This is the elevation of Cayuga Lake, which is 36 miles long, and has a maximum width of about $3\frac{1}{2}$ miles. Just below the junction of the branches from the two lakes is Lock No. 1, having a drop of $7\frac{1}{2}$ feet, and bringing the level down to that of the Erie branch of the barge canal, namely 374 feet. It is 4 miles nearly due north from Lock No. 1 of the Cayuga and Seneca branch to the junction with the Erie branch, about $1\frac{1}{2}$ miles southwest of Montezuma.

The Oswego branch follows the Oswego River, running northerly westerly 23.4 miles from Three River Point to Lake Ontario at Oswego. The fall is continuous from elevation 363 at Three River Point to Lake Ontario level, assumed by the barge canal engineers to be 244.4, making the total drop 118.6 feet. This drop is controlled by seven locks, one at Phoenix having 10.2 feet drop, two at Fulton having a total drop of 44.8 feet, one at Minetto having a drop of 18 feet, and three at Oswego having a combined drop of 45.6 feet.

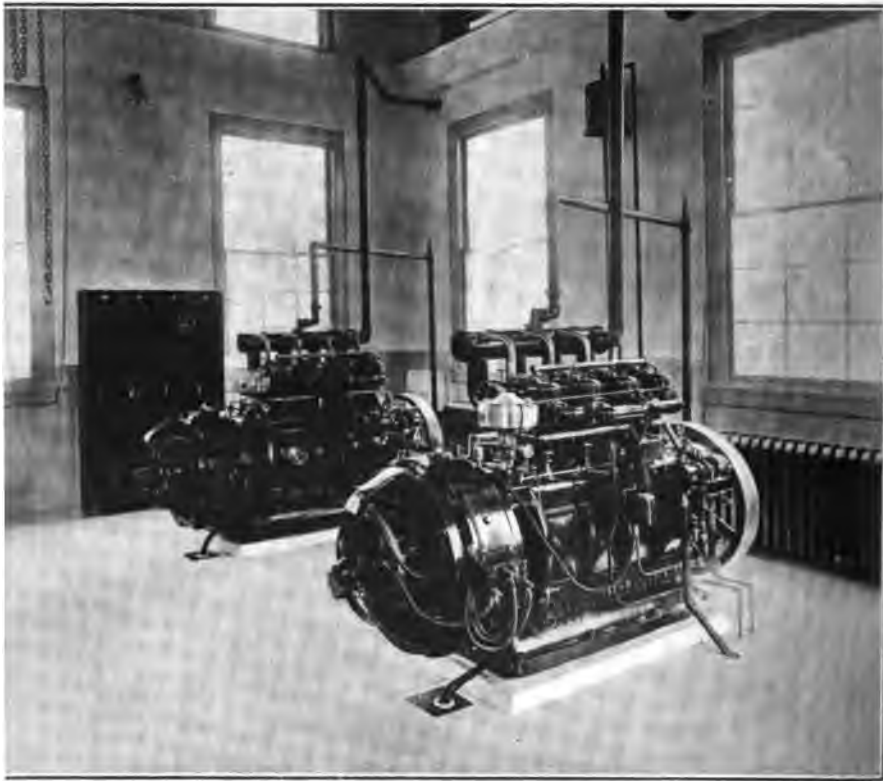
The work of reconstructing the Erie Canal, Champlain Canal, Oswego Canal, and Cayuga & Seneca Canal, to form the present barge canal system was commenced in the spring of 1905. In the spring of 1918 the entire system was open for navigation, although some work still remained to be done, mainly on the western end of the Erie branch, and on the various terminals.

Cost.—In April, 1900, the State of New York appropriated \$200,000 for a complete survey and estimate of cost of a new canal system, embracing the Erie, the Oswego, and the Champlain Canals. The surveys, plans, and estimates were completed in February, 1901, and in 1903 the people of the State voted favorably for the improvement and enlargement of these canals at an estimated cost of \$16,000,000. By another referendum vote in 1909, the Cayuga & Seneca Canal was added to the barge canal system, at an estimated cost of \$7,000,000. By a third referendum vote in 1911, \$19,800,000 was appropriated for building terminals at various municipalities throughout the State; and by a fourth referendum vote, in 1915, a further sum of \$27,000,000 was appropriated to cover the full completion of the canal system. The total appropriation, \$154,800,000, will represent very closely the cost of the New York State Barge Canal.

Traffic.—The barge canal is to be free of tolls. As yet there is comparatively little traffic upon it, and only a few boats are available for its use. The United States Government is now supervising the use of the canal for navigation purposes, and constructing barge locks to be used upon it. By such arrangements as to rates and routing of freight as is possible under Government control of commerce on both the canal and the competing railways, it is hoped that a large use of the canal will develop, relieving railway congestion and reducing the cost of transportation. It was originally intended that the canal

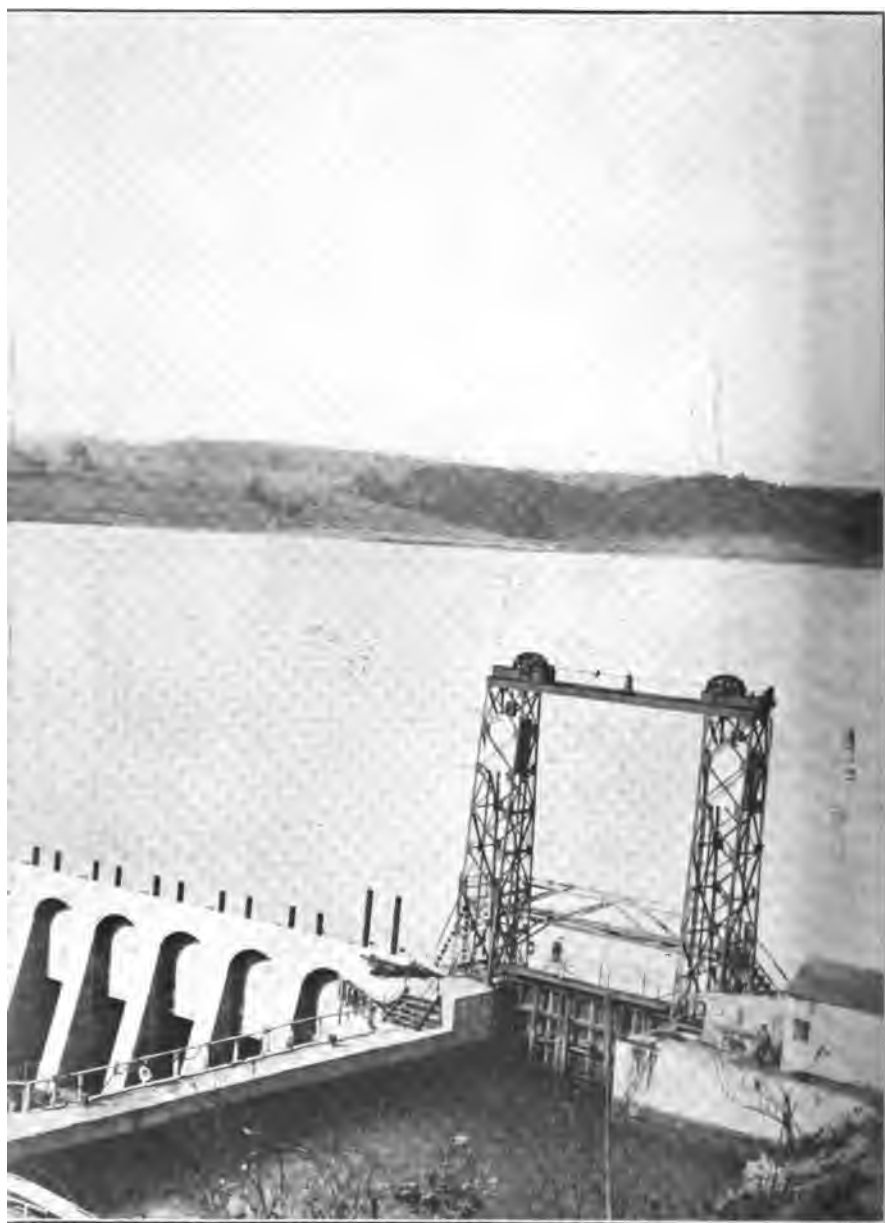


Photograph No. 33.—NEW YORK STATE BARC
Interior of Hydraulic Power House.



Photograph No. 35.—NEW YORK STATE BARGE CANAL.
Interior of Gasoline Power House.













should be navigated by self-propelled barges of 1,000 tons cargo capacity. The locks, as finally built, were considered adapted for the use of a self-propelled barge of 1,500 tons cargo capacity in tandem with a tow barge of equal capacity. Thus 3,000 tons of freight could be passed at a lockage. Six of the old Erie Canal boats of 250 tons capacity each can be accommodated at a time in a single lock. Contracts for 21 concrete tow barges to be used on the canal have been let by the inland waterways committee of the Railroad Administration. These barges are to be 150 feet long, 21 feet beam, and of 12 feet molded depth. The loaded draft is to be $9\frac{1}{2}$ feet, loaded displacement 756 tons, and cargo capacity 489 tons. Four of these barges may be locked at a time, and it is intended to tow them in groups of four. They are of open hull construction, and will cost about \$25,000 each. No figures are available on the cost of operation or maintenance of the canal.

History of New York canals.—The first work of interior waterway improvement in New York State was done in the latter part of the eighteenth century between the Hudson River and Lake Ontario, and between the Hudson and Lake Champlain, by two private companies which were chartered in 1792. Agitation for State-built canals began about 1808 and resulted in the construction of the Erie and Champlain Canals in the years 1817 to 1825. In the next decade several lateral canals were built, followed by the first enlargement of the three chief canals, a work protracted through many years, and not completed until 1862. Subsequently and prior to 1900 there occurred several partial enlargements, including one known as the "nine-million improvement." The original Erie Canal begun in 1817 and finished in 1825, was 4 feet deep, 28 feet wide at bottom, and 40 feet wide at the water surface. It was 363 miles long, had 84 lift locks and 13 guard locks, each 90 by 15 feet, and constructed of stone. Its cost was \$7,143,790. The first enlargement was made between 1836 and 1862. The waterway was made 7 feet deep, $52\frac{1}{2}$ to 56 feet wide on the bottom, and 70 feet wide at the water line. There were 72 lift locks and 3 guard locks, each 110 by 18 feet, inside horizontal dimensions. The total length of the canal was reduced to $350\frac{1}{2}$ miles. The cost of enlargement was \$31,834,041. The second enlargement was begun in 1896, when a depth of 9 feet was attempted. The work was completed at disconnected localities only, and the canal still remains for the most part as left at the end of the first enlargement, except in so far as it has been destroyed in constructing the new barge canal. Ultimately practically all the locks of the old canal were doubled to care for the enormous amount of traffic, and to provide lockage when one lock was out of commission. Practically all canal boats were towed by mules or horses on a towpath along one side of the canal.

Tolls were charged on the old canals. The old Erie Canal provided the first practicable commercial route between the Great Lakes region and the United States seaboard. It made the growth of the western part of the State practicable, and was a great aid in opening up such western States as Michigan, Ohio, Illinois, and Wisconsin. Even to-day over 75 per cent of New York State's population is to be found within 5 miles of the barge canal and the Hudson River. The early traffic on the canal was enormous for the times,

canal. This supply was augmented by the flow from the upper portion of Tonawanda Creek, which was brought across the low divide, in a canal several miles long, northerly to Oak Orchard Creek. This water now flows down Oak Orchard Creek under the aqueduct at Medina, the feeder between Oak Orchard Creek and the canal having been abandoned.

The barge canal was opened to navigation only about a year ago, and as yet no large amount of traffic has developed, so there is no actual knowledge as to the quantity of water which must ultimately be diverted into the canal from Niagara River to supply the needs of navigation. The original estimate of the average water supply which the barge canal would require from Niagara River was made by Mr. Emil Kuichling, and reported to the State Engineer and Surveyor February 12, 1901. It is as follows, not including the quantity assumed to be necessary for refilling the canal prism each spring:

	Cubic feet per day.
Evaporation, percolation, and absorption by plants.....	32,500,000
Leakage at aqueducts, culverts, and waste gates.....	2,500,000
Leakage at lock gates and valves.....	1,200,000
Loss over waste weirs.....	5,000,000
Water for power to operate locks.....	1,000,000
Water for power for electric light at locks.....	700,000
Water for lockages, at average rate of 59 per day.....	18,000,000
Water diverted for industrial uses and agriculture.....	46,000,000
Total during season of navigation.....	106,900,000

This is equivalent to an average discharge of 1237.27 cubic feet per second. It was considered that this diversion would care for an annual traffic of 10,000,000 tons of cargo. The last item in the table—namely, 46,000,000 cubic feet per day—was to include such spilling at wasteways for power uses as had been customary at Lockport, Medina, and elsewhere. Several years subsequently it was decided to increase the width of the locks from 28 to 45 feet, and the depth from 11 to 12 feet. The quantity of water required for the same number of lockages was thereby largely increased, as was also the quantity necessary to provide power for operating gates and towing boats in and out of locks, and for probable increased waste weir losses. For maximum conditions of seepage, evaporation, and lockage, it was considered that no greater supply would be necessary, provided none of the 46,000,000 cubic feet per day was spilled for industrial or agricultural uses at such times; and the value of 1,237 cubic feet per second was retained in all subsequent computations. The Barge Canal accordingly was designed with such slopes as to be able to abstract 1,237 cubic feet per second from the Niagara River at a stage of 565.5 at Tonawanda, barge canal datum, and transport from point to point so much of this as was not lost en route by seepage, evaporation, leakage at wasteway gates and aqueducts, and unavoidable spilling over waste weirs caused by winds, passing boats, or lock fillings. The quantity passing Medina under these conditions was calculated to be 967 cubic feet per second, and that entering Genesee River 606 cubic feet per second. A quantity of 606 cubic feet per second was to be abstracted from the east side of Genesee River and carried on down the long level.

At times when the requirements for seepage, leakage, lockage, etc., are less than maximum, it will not be possible to reduce the flow very much, because a quantity approximating that assumed in the computations will be necessary to maintain the proper slope, and thus provide a depth of water of 12 feet at all points on the long level from Lockport to Rochester. The excess quantities of water must be discharged at wasteways all along the line, and could not be discharged at one or two or three places only, as, for example, at Lockport, Medina, and Rochester, without either an accompanying lowering of the water surface below the 12-foot depth profile at some localities, or the use of flashboards at some of the spillways to allow for higher stages and to prevent local discharge. A careful consideration of the subject has led to the conclusion that an average diversion of 1,237 cubic feet per second of water from Niagara River at Tonawanda will provide for the maximum conditions of traffic and canal losses. It is estimated that the maximum possible annual traffic on the canal is 18,000,000 to 21,000,000 tons of cargo. Only by actual use of the canal for a long period of time can it be determined what the losses will be, what diversions will be required, or what the discharging capacity of the canal will prove to be under various conditions. It has been estimated that the maximum possible flow of water leaving Lockport in the long level will be about 1,600 cubic feet per second, except in case of a washout or of unnecessary wasting of water not far downstream from Lockport. It should be pointed out that the long level might have been constructed with the tops of the banks and waste weirs as at present, but with a depth of 2.27 feet greater at Lockport, and a level bottom all the way to Genesee River. This would have required an average excavation 1.135 feet deeper, and would have involved considerable expense, but would have produced a canal having 12 feet depth at all times without requiring a flow of water to maintain slopes. The result would very likely have been a much smaller consumption of water from Niagara River at times when traffic was light, and seepage and evaporation at minimum values.

The discharge capacity of the portion of the barge canal above Lockport is limited by two factors; first, the depth of water to be maintained in the canal; and second, the stage of Lake Erie, on which the stage of Niagara River at Tonawanda depends. Lake Erie can not fall below a stage of 570.46, United States standard datum, without the depth in the canal at Tonawanda becoming less than 12 feet. At this stage and higher stages, and with 12 feet of water on the upper sill of the locks at Lockport, the discharge of the canal at Lockport is indicated by computations to be approximately as follows:

Discharge (cubic feet per second) of barge canal at Lockport.

12 FEET OF WATER ON UPPER SILL.

Lake Erie stage, United States datum, 1903:

570.46	1, 280
571	1, 500
572	1, 900
573	2, 300
574	2, 700

¹ 12 feet depth at Tonawanda.

134 DIVERSION OF WATER FROM GREAT LAKES AND NIAGARA RIVER.

With depths of only 11½ and 11 feet maintained in the canal above the locks the discharge conditions will be approximately as follows:

Discharge (cubic feet per second) of barge canal at Lockport.

11.5 FEET OF WATER ON UPPER SILL.

Lake Erie stage, United States datum, 1908:

570.08	1,310
571	1,630
572	2,020
573	2,400
574	2,770

11 FEET OF WATER ON UPPER SILL.

Lake Erie stage, United States datum, 1908:

569.69	1,300
570	1,420
571	1,700
572	2,100
573	2,410
574	2,730

In Table No. 9 there is given the average number of days each year that the average daily stage of Lake Erie at Buffalo fell below certain elevations, during the season from May 1 to December 22, in the years 1913-1917, both inclusive. There is also given to the barge canal discharge at Lockport corresponding to each stage, under the assumption that the depth of water on the upper sill of the locks at Lockport was just 12 feet.

TABLE NO. 9.—Average number of days in navigation season, Lake Erie, at Buffalo, fell below given elevations and corresponding barge canal discharge at Lockport.

[Based on season May 1 to Dec. 22, of the years 1913-1917, both inclusive.]

TWELVE FEET OF WATER ON UPPER SILL OF LOCKS.

Elevation of Lake Erie (United States datum).	Number of days.	Corre- sponding discharge.	Elevation of Lake Erie (United States datum).	Number of days.	Corre- sponding discharge.
570.50	1	1,300	571.50	17	1,700
570.75	1	1,400	571.75	31	1,800
571	2	1,500	572	54	1,900
571.25	6	1,600	572.25	83	2,000

It will be observed that the 1,237 cubic feet per second estimated as required for navigation purposes will be available at any average daily stage likely to occur. The water diverted from the Niagara River at Tonawanda is discharged into Lake Ontario at Oswego or at intermediate points along the south shore of the lake, and so is not lost to the Great Lakes Basin, except for the portion of the diversion lost by seepage and evaporation. It is, however, lost to the Niagara River from Tonawanda to its mouth at Youngstown. It may be mentioned that the small contributions of Tonawanda and Ellicott Creeks are taken into the barge canal, except for

* 11.5 feet depth at Tonawanda.

* 11 feet depth at Tonawanda.

the portion of flow of the upper part of Tonawanda Creek which is diverted into Oak Orchard Creek, as already explained. East of Pittsford and Irondequoit Creek, and as far as Oswego, practically all the New York State drainage of the Great Lakes Basin is gathered into the barge canal and discharged down the canalized Seneca and Oswego Rivers into Lake Ontario at Oswego.

At Lockport the water used for lockages, and that which leaks past the locks, will constitute but a very small part of the water supply necessary for the long level, possibly 320 cubic feet per second. If 84 cubic feet per second is deducted as the loss from the canal by seepage and evaporation between Niagara River and Lockport, there still remains of the 1,237 cubic feet per second a volume of 833 cubic feet per second to be by-passed around the locks. Of this perhaps an average of 20 cubic feet per second will ultimately be used by the State hydroelectric plant situated at the lower lock. The waterway leading to this plant is constructed in the lock walls between the new and old flights of locks. To by-pass the 800 or more cubic feet per second of water required, the State has provided a tunnel about 15 feet square and 700 feet long on the south side of the canal and abreast of the locks, leading from an entrance and gateway just upstream from the new locks to a small, high, level basin within concrete retaining walls, and thence past gates into a structural-steel flume of large diameter and about 250 feet long, which extends down to and out over the lower level of the canal. There are other passages for by-passing this water, one on each side of the canal, but as these pertain to waterpower developments, they will be described in the section of this report devoted to "Diversions for power purposes."

The old Erie Canal did not terminate at Tonawanda, but at Buffalo. From Buffalo Harbor it followed along the river front inside of Black Rock Harbor, as has previously been noted in this report in the chapter on the Black Rock Canal. Leaving Black Rock Harbor, it passed through the guard lock, No. 72, which is located between Austin and Hamilton Streets, where there was a slight drop in the water surface. From there the canal followed a land line just east of the Niagara River to Tonawanda Creek at Tonawanda. The water surface of Tonawanda Creek was held several feet higher than at present by a dam across the creek at Tonawanda, which had its crest at elevation 570 barge canal datum. This dam was removed in the spring of 1918, and a temporary dam placed across the lower end of the portion of the old Erie Canal leading from Buffalo. The water supply for the western end of the old Erie Canal came almost entirely from Lake Erie at Buffalo, the flow being regulated at guard lock No. 72. The mean stage of Lake Erie for the years 1860 to 1910, inclusive, was 572.58 feet, United States datum. The corresponding stage of Niagara River at Tonawanda is 566.01 feet, United States datum, or 567.14 feet, barge-canal datum. When measured at Hamilton Street, Buffalo, in October, 1907, by the United States Lake Survey, the flow in the Erie Canal averaged 768 cubic feet per second. A very rough gaging of the flow at Tonawanda in the fall of 1912 showed a discharge of over 1,000 cubic feet per second. Not all of this volume reached Lockport, as there was practically always a flow over the Tonawanda Dam, as well as some spill into Niagara River at the waste weir at

Niagara Street, between Kohler and Bouck Streets, Tonawanda, and some leakage at the Tonawanda side-cut lock, as well as a small amount of seepage and evaporation along the entire route.

In a letter dated February 10, 1911, the State engineer and surveyor of New York reported to the Lake Survey that the average water requirement for the western end of the old Erie Canal was 700 cubic feet per second, which was necessary to maintain the slope and navigable depth in the long level from Lockport to Rochester, covering evaporation, seepage, and spillway losses, and a supply of 210 cubic feet per second for lockage, seepage, and evaporation east of Rochester. The requirement for lockage at Lockport was stated as 100 cubic feet per second, leaving 600 cubic feet per second to be by-passed around the locks. Of the 700 cubic feet per second passing eastward from Lockport to maintain the long level, 200 was assumed to be lost by leakage, seepage, and evaporation, leaving 290 cubic feet per second to be spilled at various wasteways along the level, notably at Gasport, Medina, Albion, and Adams Basin. It was stated that the average amount spilled at Medina was 108 cubic feet per second, and at Albion 111 cubic feet per second. Under conditions of maximum lockage, seepage, and evaporation the average total diversion was considerably exceeded. It was further stated that an additional quantity, averaging 233 cubic feet per second, was diverted from Lake Erie, solely for power purposes, being diverted around the locks at Lockport, and into Eighteenmile Creek. This matter will be considered later in connection with the description of the water power developments at Lockport.

The water supply of the Rome summit level comes from local streams north and south of the canal. The Black River Canal and its Forestport feeder have both been described in the present chapter. There are not less than 12 natural lakes and artificial reservoirs discharging into the upper end of the feeder at Forestport. By the terms of an agreement with owners of water powers on Black River below Boonville a volume of 11,000 cubic feet per minute, or 183 cubic feet per second, may be delivered continuously down Black River Canal to the south, provided 5,000 cubic feet per minute, or about 79 cubic feet per second, remain to be diverted northward. On the basis of a division in this ratio, Mr. Kuichling estimated the supply to the Rome summit level by way of the Black River Canal would be only 100 cubic feet per second. The distance from Forestport to the barge canal at Rome, as traversed by the feed water, is about 46 miles, the descent being about 700 feet, occurring largely at the 70 locks en route along Black River Canal. This supply formerly served the old Erie Canal. For the barge canal there have been constructed two large reservoirs north of the canal, known as Delta Reservoir and Hinckley Reservoir. Delta Reservoir is on the Mohawk River, about 5 miles due north of the city of Rome. It has been created by the building of a high concrete dam, and covers about $4\frac{1}{2}$ square miles when full, impounding the drainage from 137 square miles. The available water supply was estimated by Mr. Landreth to be about 150 cubic feet per second. The Hinckley Reservoir is on West Canada Creek, above the village of Hinckley, about 15 miles east of Delta Reservoir and 17 miles northeast of the nearest point on the barge canal. It was formed by the construction of a large earth dam, has an area of $4\frac{1}{2}$ square miles when full, and impounds

the drainage from 372 square miles. Hinckley Reservoir averages somewhat deeper than Delta Reservoir and its capacity is correspondingly greater. Its available supply is estimated to be about 280 cubic feet per second, assuming one-third of the flow to pass on down West Canada Creek to supply water powers between Trenton Falls and Herkimer. Water from Delta Reservoir is supplied to the Rome summit level at Rome through the Mohawk River.

Water from Hinckley Reservoir flows down West Canada Creek to Trenton Falls, where a portion of it is diverted through an artificial canal 5.7 miles long to Nine Mile Creek, through which it is fed into the summit level between Rome and Oriskany. It has been stated already in this chapter that the portion of the old Erie Canal between Butternut Creek feeder, about 5 miles east of Syracuse, and New London, on the Rome summit level, has been retained as a navigable feeder and connected with the summit level by a new junction lock. There are five feeders bringing water from the south into this portion of the old Erie Canal, all of which were constructed years ago for the purpose of feeding the old canal. They are the following: Orville feeder, drawing from Butternut Creek and Jamesville Reservoir; Fayetteville feeder, delivering from Limestone Creek and De Ruyter Reservoir; Chittenango feeder, drawing from Chittenango Creek, Erieville Reservoir and Cazenovia Lake; Cowasselon feeder, delivering from Cowasselon Creek; and Oneida feeder, delivering from Oneida Creek. It is important to note that most of the water supply to De Ruyter Reservoir is derived by diverting into it the flow of the upper portion of Tioughnioga River, which is a tributary of the Chenango River, which in turn is a branch of the Susqueshanna, and so discharges into Chesapeake Bay. The total supply to the Rome summit level from this source was estimated by Mr. Kuichling to be about 35 cubic feet per second. Another feeder of the summit level is Oriskany Creek, which enters the Mohawk River from the south about $7\frac{1}{2}$ miles east of Rome. This creek rises about 25 miles due south of Rome. The upper portion of its drainage area, together with that of some of the upper branches and tributaries of the Chenango River, was formerly used to supply the summit level of the Chenango Canal, and an extensive system of storage reservoirs was established by the State in this locality.

On the abandonment of the Chenango Canal, however, its summit level and water resources were retained to feed the old Erie Canal through Oriskany Creek. The reservoirs, all of which are on streams originally tributary to the Chenango River, are as follows: Eaton Brook Reservoir, Hatch Lake Reservoir, Bradley Reservoir, Kingsley Brook Reservoir, Madison Brook Reservoir, Leland Pond Reservoir, and several small ponds. These all discharge into the summit level of the Chenango Canal, which, in turn, discharges into the headwaters of Oriskany Creek. The water supply from this source, as estimated by Mr. Kuichling, was about 35 cubic feet per second. The total estimated supply for the Rome summit level is the sum of the quantities given above, or 600 cubic feet per second. The estimated water supply required for the summit level is about 440 cubic feet per second. It is to be noted that of the 600 cubic feet per second constituting the supply, 430 cubic feet per second, the portion from Delta and Hinckley Reservoirs, is naturally tributary to the Hudson River, while of the 170 cubic feet per second remainder at least 35 cubic

feet per second is naturally tributary to the Susquehanna River, leaving only 135 cubic feet per second naturally tributary to the Great Lakes. It is estimated by Mr. Landreth that the water supply required just west of the summit level for conditions pertaining to an annual traffic of 10,000,000 tons of cargo, including evaporation, seepage, leakage, spillway losses, lockages, and lock operation, is 213 cubic feet per second, and that the corresponding requirement just east of the summit level is 219 cubic feet per second. These values are so nearly identical that they may be considered equal, each 220 cubic feet per second. It is evident, then, that none of the water tributary to the Great Lakes escapes by way of the barge canal into the Mohawk Valley, but that, on the contrary about 85 cubic feet per second is gained by the Great Lakes Basin, part of this coming from the Mohawk Basin, and part from the eastern headwaters of the Susquehanna River.

Photographs Nos. 29 to 46, inclusive, illustrate various features of this notable waterway. Explanations and descriptions are given beneath the pictures.

6. ST. LAWRENCE RIVER CANALS.

Description of St. Lawrence River.—The quantities of water diverted from the St. Lawrence River by the various canals are very small, with exception of the Massena Canal, where the diversion is very large. In every case the water diverted is returned to the river again within a distance of $1\frac{1}{4}$ to $10\frac{1}{4}$ miles. The diversion by the Galop Canal is between 500 and 1,000 cubic feet per second, on the average, of which 200 or less is for navigation use. The diversion by the Morrisburg Canal is between 1,000 and 1,500 cubic feet per second, of which possibly 200 is required for navigation purposes. In both these instances the balance of the diversion is used for power development. The navigation requirement does not exist in winter time, but power is, in general, developed the year around. The Farran Point Canal diverts probably less than 50 cubic feet per second on the average, all for navigation use. The diversion by the Cornwall Canal appears to average somewhat less than 3,000 cubic feet per second. Of this, during the navigation season, an average of perhaps 300 cubic feet per second is required by navigation. The remainder is utilized in power development.

The diversion through the Massena Canal is entirely for power development, and will be treated in section (c) of this report. In the same section the power features of the Galop, Morrisburg, and Cornwall canals are presented. The flow in Little River, at Waddington is described in this section also.

In the following paragraphs the navigation canals of the St. Lawrence River above St. Regis are described, with special reference to the navigation features. On Plates Nos. 9 and 10 these canals are shown in their relationship to certain sections of St. Lawrence River.

The St. Lawrence River is the outlet of the Great Lakes to the sea, debouching from the northeasterly corner of Lake Ontario and flowing thence in a northeasterly direction 700 miles to Anticosti Island in the Gulf of St. Lawrence. It is nearly 1,200 miles from Lake Ontario to the open sea at the Strait of Belle Isle.

For a distance of 62 miles, from Tibbetts Point at the head of the St. Lawrence to Ogdensburg, N. Y., the fall in the water surface is only 0.87 foot at mean stage, and from there to Lock No. 27 at the head of the Galop Rapids, 6 miles, the fall at mean stage is 1.32 feet more. Throughout this reach the river is broad, and, for the greater portion of the distance, from the lake down to Brockville, Ontario, is divided into channels by a great number of islands. There is a natural navigable channel 28 feet deep or over, except for the possibility of undiscovered shoals, and 400 or more feet wide, which is wholly in United States waters except for about $7\frac{1}{2}$ miles, from Cross-Over Island through the Brockville Narrows.

From Ogdensburg to Montreal, 120 miles, the river is generally narrow and swift, and is much less cut up by islands. All the rapids of the St. Lawrence occur in this reach, the total fall at low stage being about 224 feet, or from elevation 242 to elevation 18.

Fifty miles below Montreal is the head of Lake St. Peter, the most upstream point at which tide is observable. Except for this lake, the reach of river from Montreal to Quebec, 150 miles, is of moderate width and has few islands. From Quebec to the Gulf the stream is very broad. Channel improvements have secured a depth of 30 feet from Montreal to the sea, the dredged channel extending to Father Point, 175 miles below Quebec. The improved channel is 450 feet wide between Montreal and Quebec, being from 600 to 750 feet wide at bends. Below Quebec it is 1,000 feet wide.

At St. Regis, N. Y., opposite Cornwall, Ontario, the St. Lawrence passes wholly into Canadian territory and ceases to be a boundary stream, 114 miles from Lake Ontario. It is to be noted that in the total distance from Lake Ontario to the sea, United States waters are comprised in only the upper one-tenth thereof, the remaining nine-tenths being wholly Canadian waters. The mean river elevation at Lock No. 15 at Cornwall is 153.42, showing a fall from Lake Ontario at Tibbetts Point of 92.66 feet.

The mean elevation of Lake Ontario at Oswego, N. Y., for the years 1860 to 1917, both inclusive, is 246.18 feet on United States standard datum. The discharge of the St. Lawrence River at this stage, as determined at two gauging sections just below Iroquois, Ontario, is 241,000 cubic feet per second. At this stage the change in discharge per foot change in stage is approximately 21,500 cubic feet per second.

At Galop Rapids the river has a fall of about 9 feet in 3 miles, from Adams Island at the head of Galop Canal to Lotus Island. The channel north of Galop Island, in Canadian waters, is navigable by light draft boats. The south channel, which is in American waters, is not navigable.

From Lotus Island to Iroquois, about $5\frac{1}{2}$ miles, there is a fall of about $6\frac{1}{2}$ feet. The river follows a tortuous channel and the current is swift. This is all properly a part of the Galop Rapids, although the swiftest portions, namely, those abreast of Cardinal, Ontario, and Point Iroquois, are frequently designated, respectively, as the Cardinal Rapids and the Point Iroquois Rapids. The Galop Canal, described later, provides for passing navigation around these rapids.

It is $4\frac{1}{2}$ miles from Lock No. 25, at Iroquois, to Lock No. 24, at the head of Morrisburg Canal, abreast the head of Rapide Plat, and the fall in this distance is approximately 3 feet. The river has but a

single channel, and the current is swift. This is the most difficult portion of the river for upbound vessels, where a canal is not provided.

In the Rapide Plat there is a fall of about 12 feet in approximately $3\frac{1}{2}$ miles. This rapids has a ruling depth of about 12 feet at low water, and a sinuous channel. Ogden Island, which is United States territory, forms the south shore of this rapids. The Morrisburg Canal follows the Canadian shore the full length of the rapids.

Between Ogden Island and the main American shore is the "Little River," which is shallow, narrow, and winding, and is not navigable, except by small steam and motor boats, above and below a dam which crosses it at Waddington, N. Y. The dam is a dilapidated timber and rock structure about 950 feet long and 12 feet high. At present the flow through Little River is approximately 1.1 per cent of the total St. Lawrence discharge.

From Lock No. 23, at the foot of Morrisburg Canal, at Morrisburg, Ontario, to the Farran Point Canal, $9\frac{1}{4}$ miles, the fall is about $7\frac{1}{2}$ feet. The channel is winding and the current generally swift.

The Farran Point Rapids, on the Canadian side of Croil Island, is little more than a mile long, but is narrow and swift, having a fall of 4 feet. Farran Point Canal, along the Canadian shore, overcomes this rapids.

It is 5 miles from Lock 22, at the foot of Farran Point Canal to the head of the Cornwall Canal, and the fall in water surface is 0.5 foot at mean stage. In this reach the river is separated into two channels by large islands, and the slopes in the two channels differ considerably.

The Long Sault Rapids commence at the head of the Cornwall Canal, near Dickinson's Landing, Ontario, and extend about $10\frac{1}{4}$ miles by the main channel to Lock No. 15 at Cornwall, Ontario. The total fall is 47.4 feet, the fall in the swiftest portion, however, being $28\frac{1}{2}$ feet in less than 3 miles. Several large islands divide the river into channels through this reach. What is known as the "South Sault Rapids" is the American channel between the American shore and Long Sault Island. This channel is narrow and sinuous, the current is very swift, and navigation is impracticable. Near the upper end of the South Sault, and not far upstream from the head of the Long Sault Rapids, the Massena Canal diverts water on the United States side for power development. The Cornwall Canal extends along the Canadian shore the full length of the Long Sault Rapids.

The only bridge across the St. Lawrence where it borders the United States is at Cornwall. This is a single-track bridge of the New York & Ottawa Railway. There are two parts to this bridge, one across the channel to the north of Cornwall Island, the other across the channel south of the island. That across the south or American channel consists of three spans. The middle span is 372 feet, and the two end spans are 370 feet each, all from center to center of piers. The piers are about 12 feet wide at the water line. The spans are fixed and have $37\frac{1}{2}$ feet of headroom above high water during the season of navigation.

The bridge across the north channel also consists of three spans, the middle span being 420 feet long, the north span 212.5 feet, and the south span 210.5 feet, all from center to center of piers, with the

piers about 16 feet wide at the water line. The middle span, which covers the part of the river now used by downbound passenger boats, has 60 feet of headroom at high water. There are no lights displayed nor buoys marking the approach, because the bridge is at the foot of Long Sault Rapids, and this part of the river is navigated only in daylight and by special boats. There is a draw span carrying this railway over the Cornwall Canal.

For the purposes of this report the character of the St. Lawrence below St. Regis is of little interest. It may be noted that Lake St. Frances, an expansion of the river, commences just below St. Regis and extends for 30 miles to Coteau Landing, the fall in this reach being about half a foot. From Coteau Landing the next 14 miles of river is practically a continuous rapids, although the swifter portions are named in order Coteau Rapids, Cedars Rapids, Split Rock Rapids, and The Cascades. The total fall is about 84 feet. It may be added parenthetically that there is a large modern power development at Cedars Rapids, a large proportion of whose power is transmitted to the plant of the Aluminum Company of America, at Massena, N. Y. The Soulanges Canal overcomes these rapids for navigation, extending along the north bank from Coteau Landing to Cascades point. On the south bank is the Beauharnois Canal, extending from Valleyfield to Melocheville. This canal was abandoned for navigation use a few years ago and is now used for power development. Lake St. Louis, another expansion of the St. Lawrence, extends from Cascades Point to Lachine, 15 miles, the fall being about 2 feet. The Ottawa River discharges much of its flow into this lake. The Lachine Rapids extend 9 miles from Lachine to Montreal and have a fall of 45 feet. This rapids is overcome by the Lachine Canal on the north bank of the river.

Generally speaking, the St. Lawrence River and canals from Ogdensburg to Montreal will accommodate vessels 255 feet long, 42 feet beam, and drawing 14 feet of water. Except for a few ruling shoals a draft several feet deeper could be carried in the river portions between the canals. At the upper end of Galop Rapids the river channel has been improved to accommodate an 8-foot draft. In the Rapide Plat a draft of 14 feet is accommodated at mean stage, and 12 feet at low stage. In the Long Sault Rapids the limiting depth is about 8 feet at mean stage.

Between Ogdensburg and the head of Cornwall Canal there is practically no navigation between dark and dawn, except on clear moonlight nights. There are no river lights, and the arrangements for illuminating locks and canals are meager.

Navigation through the St. Lawrence River and its canals is greatly interfered with by ice conditions, being closed on the average from December 3 to April 27, 144 days per annum, as shown by the records for 50 years.

Galop Canal.—The Galop Canal has already been described as being the most upstream of the St. Lawrence canals, and as overcoming the Galop, Cardinal, and Point Iroquois Rapids, extending along the Canadian shore from Adams Island, at the head of Galop Rapids, to Iroquois, Ontario, just below Point Iroquois. It is $7\frac{1}{2}$ miles long, 14 feet deep, 80 feet wide at the bottom, and 144 feet wide at the surface. About three-fourths mile below the head of

the canal there are two locks abreast of each other. That nearest the river is No. 28, and is known as the "lift lock." It connects this short upper reach of the canal with the river above Cardinal. It is 303 feet long, 45 feet wide at the bottom, 47½ feet wide at the top, has 14 feet of water over the miter sills, and has a lift of about 5 feet. The other lock is No. 27, and is called a guard lock. There is usually a lift of 1 or 2 feet at this lock, depending on the river stage and the depth of water maintained in the canal below. Lock 27 is 270 feet long, available length for boats 255 feet, 45 feet wide at bottom, 46 feet 10 inches wide at the top, and having 14 feet of water on the sills. At the lower end of the canal, at Iroquois, is Lock No. 25, which is 800 feet long, 50 feet wide, and has 14 feet of water on the upper sill and somewhat greater depth on the lower sill. The lift is approximately 14 feet, and varies somewhat with river stage and canal level. The locks are operated by hand.

Practically all upbound vessels enter Lock 25 and proceed up the canal. A few fast passenger boats habitually run up the river past Cardinal and enter the canal through Lock 28. Occasionally a fast freight boat takes this same course when otherwise it would be delayed waiting for Lock 25. A few small boats run the rapids all the way when downbound. All other downbound vessels enter the head of Galop Canal, lock out into the river at Lock 28, and run down the remainder of the rapids. It is reported that small swift steamers sometimes run up the entire rapids in spring before the canal is opened to navigation.

There are two bridges across the canal, both of which are hand-operated, swing bridges having a clear span across the canal. The bridge at Cardinal carries a highway and a spur-track. When closed it has a clear headroom of some 15 to 20 feet. The bridge at Iroquois, just upstream from Lock 25, carries a highway, and has only a few feet of headroom when closed.

The old Galop Canal followed nearly the same route as the present canal, except at Cardinal. The present canal follows a more direct route through a deep cut behind the town. The old canal follows the curve of the shore around in front of the town, and the upstream half of this old route is still used as a power canal. The old lock No. 26, still exists, except for the gates, and is located abreast the center of the town. There is no new lock having this number, as the intermediate lift was eliminated in the new canal. Old Lock No. 27, which was about half a mile upstream from the present Lock No. 27, was removed during the reconstruction. Old Lock No. 25, without its gates, still exists at Iroquois, not far from new Lock No. 25. It forms part of the present tailrace from the waste weir and power houses.

The original cost of construction of the Galop Canal is not known. The cost of enlargement was \$6,121,214. The cost of maintenance and operation is not known for this canal separately. For the Galop, Morrisburg and Farran Point canals taken together it will be given further on.

The freight transported in this canal in the three years 1915, 1916 and 1917 averaged 3,700,000 short tons per annum, about three-quarters of which was eastbound. The number of vessel passages was, in 1915, 8,641; in 1916, 8,325; in 1917, 8,701.

The diversion of water from the St. Lawrence River through this canal is between 500 and 1,000 cubic feet per second, of which 200

cubic feet per second or less is for navigation purposes. The balance is used developing power, as will be explained in Section C of this report. A little of this diversion is returned to the river at Lock 28, a considerable portion at Cardinal, and the remainder at Iroquois.

Just upstream from the Galop Canal is an artificial channel named the North Channel, which was constructed by Canada as an aid to navigation. It is $2\frac{1}{2}$ miles long, 300 feet wide, and 16 feet deep, and cuts through Spencer and Drummond Islands. Its cost was \$1,718,779. Its construction would have caused a permanent lowering of the river above, and of Lake Ontario, had not a pier or breakwater been extended into the river from its upstream end in such manner as partially to shut off the river flow. This channel and pier have caused a redistribution of the river flow, but no diversion of water from the river.

In connection with this improvement a dam was constructed across what is known as the "Gut," between Adams and Galop Islands. This dam has raised the level of Lake Ontario approximately half a foot.

Photograph No. 47 shows the waste weir and gates beside No. 27. Photograph No. 48 is of the canal prism with the river in the background.

Morrisburg Canal.—The Plat Rapids, or Rapide Plat, previously described, are overcome for navigation by the Morrisburg Canal which is $3\frac{1}{2}$ miles long, and extends along the Canadian shore from the head of the rapids to Morrisburg, Ontario. This canal has a depth of 14 feet on the lock sills, and also in the canal prism which is 80 feet wide on the bottom, 152 feet wide at the water surface, and is somewhat enlarged on the curves. The total lift of about $11\frac{1}{2}$ feet is overcome by two locks each 270 feet long. Lock No. 24 is about 1,000 feet within the head of the canal and is styled a guard lock, although ordinarily it has a lift of 1 to 3 feet. It has a bottom width of 45 feet and a top width of 46 feet 11 inches. Lock No. 23, at the foot of the canal, is the lift lock proper. It has a bottom width of 44 feet 2 inches and a top width of 46 feet 11 inches.

Old Lock No. 24, without gates, is abreast the new lock, on the river side, and forms part of the wasteway bypass channel around the new lock. Old Lock No. 23 is near the new lock, at Morrisburg, on the land side. It is still in commission and is used occasionally. Its length is 200 feet, available length for boats 175 feet, breadth 45 feet, and depth of water on the miter sills 9 feet.

All the locks are operated by hand, and all have the filling and emptying valves in the gates.

There are no bridges across this canal.

All upbound vessels use the canal. All downbound vessels run the rapids except during seasons of very low water, when the deeper draft boats pass down the canal.

The original cost of construction is unknown. The cost of enlargement was \$2,158,242. The cost of maintenance and operation is not known for this canal separately.

The freight tonnage transported and number of vessel passages are the same as for the Galop Canal for upbound boats, and considerably less for downbound boats.

The diversion of water from the St. Lawrence River through this canal is between 1,000 and 1,500 cubic feet per second, of which possibly 200 cubic feet per second is used for navigation requirements. The remainder is used in power development, as will be explained in section (c). All this water is returned to the river at Morrisburg.

Photograph No. 49 shows the largest size St. Lawrence freight steamer ready to leave Lock 24, upbound.

Farran Point Canal.—The Farran Point Rapids, previously mentioned, is navigated by all downbound boats except the few taking the American channel to Richards Bay. All upbound vessels take the Farran Point Canal which extends along the Canadian shore abreast of the rapids.

This canal is $1\frac{1}{2}$ miles long, 90 feet wide at the bottom, 154 feet wide at the water surface, and is 14 feet deep. There is one lock, No. 22, which is located at the downstream end of the canal. It is 800 feet long, 50 feet wide, has 14 feet of water on the sills, and has a lift of approximately $3\frac{1}{2}$ feet.

On the land side of this lock is old Lock No. 22, which is 200 feet long, 45 feet wide, and has 9 feet of water on the sills. Both locks are at the town of Farran Point.

The locks are operated by hand.

There is no bridge across this canal.

The cost of enlargement was \$877,091.

All upbound freight passing through Galop Canal passes through this canal also. Practically no downbound freight enters this canal.

The diversion of water is all for navigation and probably does not average as much as 50 cubic feet per second. It is simply diverted around the rapids for a distance of $1\frac{1}{2}$ miles.

The three canals just described, namely, Galop, Morrisburg, and Farran Point, are known collectively as the Williamsburg group. The original cost of construction of all three was \$1,320,656, which was expended prior to 1868. The enlargement began about 1885 and was completed about 1908. The total cost to March, 1916, of operation and maintenance of all three canals was \$1,511,903. The income during the same period was \$297,559.

Cornwall Canal.—The Cornwall Canal overcomes the Long Sault Rapids, extending along the Canadian shore of the river from just below Dickinson Landing 11 miles to Cornwall. It is 90 feet wide at bottom, 154 feet wide at the water surface, and 14 feet deep. About $2\frac{1}{2}$ miles of its length is considerably wider, following the natural channel between Sheek Island and the north main shore.

The total lift, which is 48 feet, is overcome by 6 locks, each 270 feet long, 45 feet wide, and having 14 feet of water on the miter sills. Of these, Lock No. 21 is about $\frac{1}{2}$ mile within the head of the canal. From Lock 21 it is about 5 miles to a guard gate which is a short distance above Lock 20. It is about $1\frac{1}{2}$ miles from Lock 20 to Lock 19, and nearly the same distance from Lock 19 to Lock 18. Locks Nos. 17 and 15 are at Cornwall, at the downstream end of the canal. There is no new lock No. 16. The lift at Lock 21 is usually only a few feet. At the other locks the lifts are about as follows: No. 20, 7 feet; No. 19, 6 feet; No. 18, 7 feet; Nos. 17 and 15, 14 feet each. The locks are operated electrically, and the canal and locks are lighted by electricity.

The old locks are still available, with the exception of No. 21. They are each 200 feet long, 45 feet wide, with 9 feet of water on the miter sills. Each old lock is abreast of the new lock of corresponding number, except at the lower end of the canal, where old Locks Nos. 15, 16, and 17 are located near the two new locks.

The single-track drawbridge of the New York & Ottawa Railway which crosses the canal just above Cornwall has already been mentioned. There are also two highway swing drawbridges across the canal, one at Cornwall and one at Mille Roches. These have center piers in the canal.

A few specially constructed passenger steamers shoot the Long Sault Rapids. All other vessels, both upbound and downbound, take the canal.

The original cost of the canal was \$1,945,625. Cost of enlargement was \$5,300,679. Cost of operation and maintenance to March, 1916, was \$3,102,415. Receipts to the same date were \$592,038.

The freight transported in this canal in the three years 1915, 1916, and 1917 averaged 3,700,000 short tons per annum, about three-fourths of which was eastbound. The number of vessel passages was, in 1915, 8,641; in 1916, 8,325; and in 1917, 8,701.

The amount of water diverted from St. Lawrence River by the Cornwall Canal appears to average roundly about 3,000 cubic feet per second. Of this, during the navigation season, an average of perhaps 300 cubic feet per second is required for navigation uses. The remainder is utilized in power development, as will be described in section (c) of this report. The diverted water is returned to the river partly at Mille Roches and partly at Cornwall, all within a distance of 5 to 11 miles of the point of diversion.

7. PROPOSED ERIE & ONTARIO SANITARY CANAL.

The Erie & Ontario Sanitary Canal Co. proposes to construct a combined ship, sanitary, and power canal from Lake Erie to Lake Ontario, and to divert 26,000 cubic feet of water per second through it. The route is shown on Plate No. 6.

Description of canal.—The proposed canal is to start from a new harbor south of Lackawanna, N. Y., where new breakwaters and piers are proposed, extending from Woodlawn Beach out into Lake Erie about 4 miles to Seneca Shoal. At the east end of the harbor a lock is to be provided for lowering vessels about 8 feet into the head of the canal. From this lock the route as planned starts toward the east, turns north on a radius of about 15,000 feet, and runs along the eastern outskirts of Buffalo through Hamburg, West Seneca, Cheektowaga, and Amherst Townships. In Pendleton Township it crosses the New York State Barge Canal at grade. It then passes through the west edge of Lockport Township, to the top of the Niagara escarpment, just west of the "Lockport Gulf." Here a pair of enormous balanced lift locks of novel design and unprecedented dimensions are to overcome the drop of 209 feet to the level below. The canal then crosses the "Ontario Plain" at an elevation of about 351 feet, through the township of Newfane, to another pair of lift locks, which serve the drop of 104 feet to the level of Lake Ontario in Eighteenmile Creek, about 2 miles from its mouth.

A large harbor is planned to be constructed at Olcott, at the mouth of the creek. North of the barge canal the line follows very closely the Tonawanda-Olcott route projected by the Board of Engineers on Deep Waterways, the main canal is 30 feet deep throughout, and has a berm 5 feet above water level on each side, the berm along one side being 10 feet wide while on the other side it is 40 feet wide. From Lake Erie to the point where the river branch from Tonawanda and Black Rock enters, the cross sections are designed to be as follows: In rock section the bottom width is 250 feet, and the side slopes 10 on 1 both above and below the berm. Overlying earth is in every case given a slope of 1 on 2, and a berm is left at the rock surface. In sections partly earth and partly rock, if retaining walls are used, the standard rock section is adopted up to rock surface, and vertical faced retaining walls extend from the rock surface up to the berm 5 feet above water line, the excavated areas behind the walls being backfilled. In sections partly in earth and partly in rock, where no retaining walls are used, and in sections wholly in earth, the bottom width is 200 feet, the side slopes are 1 on 2, and a berm 10 feet wide and 5 feet below water surface is provided on each side of the canal. From the River Branch junction to Lake Ontario the bottom width for each type of section is 50 feet greater, the other characteristics remaining unchanged. Available depth of water in the locks is to be 30 feet. The total length of the main canal, exclusive of the harbors, is 40 miles. It is $17\frac{1}{2}$ miles from Lake Erie along the route to the River Branch junction, $3\frac{1}{2}$ miles from there to the barge canal crossing, 8 miles further to the high twin locks, and 9 miles between the two sets of twin locks. The excavation is very heavy and is largely in rock, the overburden reaching a maximum of approximately 140 feet.

A branch canal starts at Black Rock and follows the line of the old Erie Canal to Twomile Creek, then turns eastward along the general line of the "State Ditch" and Ellicott Creek and joins the main canal near Getzville. This canal has a depth of 12 feet, a bottom width of 100 feet, and side slopes of 1 on 2 with a 10-foot berm on each side 5 feet under water and another 10-foot berm on each side 5 feet above water. The length of the branch canal is $13\frac{1}{4}$ miles.

Diversion.—Of the proposed 26,000 cubic feet per second discharge through the canal, 4,800 is to go through the Black Rock Canal and the River Branch Canal, the remaining 21,200 cubic feet per second entering the main channel south of Lackawanna. In each part of the system the velocity will be approximately 3 feet per second. In the greater part of the ship canal, which is through rock, this velocity will delay upbound vessels somewhat, but not excessively. The case is different, however, in the 7 or 8 miles of earth section. Mr. Alfred Noble, in his studies for the Board of Engineers on Deep Waterways, stated that the backwash due to vessels navigating an earth section of a canal should not exceed 3 feet per second, and that a velocity of $3\frac{1}{2}$ feet per second would cause excessively great cost in maintaining the banks. In the earth sections of this canal the backwash from the slowest upbound boat, added to the current of the canal, will produce a velocity along the banks exceeding this value, and with large steamers moving at 4 miles per hour the

current along the banks would amount to 4.2 feet per second. As economical operation requires ship speeds of 8 miles per hour or thereabouts, it is evident that the earth section as designed is entirely inadequate. The river branch is designed to serve as an extension of the barge canal system, and for the type of boat employed on this system a current of 3 feet per second is much too great. By enlargement of various sections of the canal these difficulties could be overcome, but only at considerable expense.

The grade crossing near Pendleton of the ship canal and New York State Barge Canal affords a weak point in the proposed scheme. A volume of flow of 26,000 cubic feet per second is to be discharged into the crossing by the ship canal, and an equal volume abstracted on the opposite side. Similarly a flow of perhaps 1,200 cubic feet per second is contributed by the barge canal on one side and abstracted on the other. The resulting eddies and cross-currents would seem to render the crossing difficult of navigation, particularly by strings of barges in the barge canal. An expensive structure could probably be designed which would protect the crossing by guard gates and carry most of the water beneath the crossing through inverted syphons, or the cross currents could be reduced by excavating a large and expensive basin at the junction. This grade crossing would be very much more difficult than the grade crossing of the barge canal and Genesee River at Rochester, partly because the Genesee is very wide at the crossing, but mostly because the volumes of flow to be handled are almost always so very much smaller in the Rochester case.

Objections.—There are two fatal objections to the proposition as a ship canal. The first is its great length as compared to other available routes. If portions of the Niagara River are utilized the artificial ship canal between Lakes Erie and Ontario need be only 8 miles long by the LaSalle-Lewiston route, or 25 miles long by the Tonawanda-Olcott route, as these routes were projected by the Deep Waterways Board. From Lewiston to Lake Ontario the Niagara River is wide and deep, and of moderate current, requiring but the removal of a small shoal at its mouth to make it readily navigable by deep draft vessels. Above LaSalle the upper Niagara River requires only a moderate amount of improvement to make it navigable for 30-foot draft with far greater speed and safety than any ship canal. The Deep Waterways Board reported that "between Buffalo and a point common to the two routes in Lake Ontario * * * in a 30-foot channel a steamship of 27 feet draft would be one hour and forty-three minutes longer by the Tonawanda route. Since the cost of maintenance of the Lewiston waterway would be less than for the route from Tonawanda to Olcott, the interest and expense accounts will be much less for the former, and as the actual time saved by a steamship on the Lewiston route would be from 11 to 16 per cent of the time of passage, it is evident that both economy in construction and cost of transportation definitely determine the Lewiston waterway as the preferable route." The proposed Seneca Shoal-Olcott Route of the Erie & Ontario Sanitary Canal Co. has a length of 40 miles. Every reason which makes the LaSalle route better than the Tonawanda route applies with double force to a comparison between the LaSalle-Lewiston and the Seneca Shoal-Olcott routes.

The other fatal objection is the fact that the proposed canal route intersects every railroad and road entering Buffalo from the west, south, and east, at each of which crossings a drawbridge would be required unless the crossings were abandoned. This is probably the most serious objection of all.

North of the State of Georgia the only low pass through the Appalachian Range from the Atlantic seaboard to the interior of the United States is by way of the valleys of the Hudson and Mohawk Rivers. The most important rail routes from New York and New England follow this pass, and they all enter Buffalo, which, because of its strategic position at the junction of the western end of this pass and eastern end of the chain of upper Great Lakes, has become one of the largest, most important, and also most congested railroad centers in the United States. The proposed canal cuts every one of the great lines of communication between the East and West through this pass, and cuts some of them twice. In the first 15 miles from Lake Erie it intersects 10 electric railroad tracks, 21 highways having no trolley tracks, and 52 steam railroad tracks.

It is estimated that a total of more than 70 separate drawbridges will be required for the entire route. A drawbridge over a ship canal is always a source of delay to traffic both over the bridge and in the canal. As it is impracticable for large vessels to stop in canals they are customarily given right of way, and land traffic is accordingly delayed. Notwithstanding having the right of way, steamers usually find it necessary to reduce speed to a minimum in the vicinity of drawbridges, and thus suffer considerable delay. Occasionally the bridge operating mechanism fails to work promptly, and then serious accidents often occur. In a current of 3 feet per second the difficulties would be intensified. Downbound vessels would not have steerage way unless making at least 4 to 5 miles per hour with respect to the bank. At such speed they could not be stopped quickly. In brief, such a condition as would necessarily prevail in the first 15 miles of the route from Lake Erie would be intolerable both from the standpoint of the railroads, and also from that of navigation.

Other objections are the lowering of Lake Erie 1.18 feet at mean stage which the direct diversion proposed would cause, and the production of excessive currents in the present Black Rock Canal. The first of these conditions could be remedied by costly remedial works; the second by an expensive enlargement of the Black Rock Canal.

As far as navigation is concerned, therefore, this proposition is not believed to be worthy of further consideration. From the standpoint of sanitation it is treated in section (b), and as a power development enterprise it is dealt with at considerable length in Section F.

8. OTHER PROPOSED NAVIGATION CANALS, LAKE ERIE TO LAKE ONTARIO.

Aside from the new Welland Ship Canal, now partially constructed, and the proposed Erie and Ontario Sanitary Canal, the proposed routes of navigation canals connecting Lakes Erie and Ontario have contemplated using portions of the Niagara River.

Attention is directed to Plate No. 6, which is a map showing Niagara River in its relation to the Welland Canal and to various

proposed canals, including that of the Erie and Ontario Sanitary Canal Co.; and also to Plate No. 11, which gives profiles of the Niagara River.

Before proceeding to consider the various proposed canals, a brief description of Niagara River and the surrounding terrain will be given.

Description of Niagara River.—The country traversed by the Niagara River lies in two plains; separated by a steep bluff called the Niagara escarpment. The upper plain has an undulating surface with a general elevation of 600 feet above sea level. The lower or Lake Ontario plain is comparatively smooth except where streams have washed out narrow valleys. From its southern edge, which has an elevation of 380 to 400 feet above sea level, it slopes northward to an elevation of about 260 feet at the lake shore, with low bluffs 10 to 30 feet high. A contour map compiled from United States Geological surveys and other sources is published in House Document No. 149, Fifty-sixth Congress, second session. (Report of the Board of Engineers on Deep Waterways, Plate No. 92.)

The Niagara River forms the natural outlet of Lake Erie at Buffalo, discharging the surplus waters into Lake Ontario at Youngstown, N. Y. It is 37 miles long by the channel on the American side of Grand Island, and 33 miles long by the channel on the Canadian side of Grand Island. The total fall in water surface from lake to lake averaged 326.35 feet for the years 1860 to 1917, both inclusive. Of this total fall about 162 feet is the sheer drop of Horseshoe Falls. The discharge of the river varies from about 110,000 to 400,000 cubic feet per second, depending on the stage of Lake Erie. At the average stage for the years 1860 to 1917, inclusive, namely, 572.53, the discharge is 208,000 cubic feet per second. The increment of discharge per foot rise of lake, near mean stage, is 22,000 cubic feet per second.

Leaving Lake Erie the river flows over a limestone ledge in a stream about 1,600 feet wide and of 15 feet maximum depth at its most restricted section. At this point the velocity approximates 8 miles per hour. In a distance of $3\frac{1}{2}$ miles from the head of the river to the foot of Squaw Island the fall in water surface is approximately 5.1 feet, varying somewhat with the stage of Lake Erie. This section of the river acts as a control on the discharge of the river, and is equivalent in its hydraulic effect to a submerged weir. Changes in water surface elevation at the foot of Squaw Island have about seven-tenths as much effect on the discharge as equal changes on Lake Erie have. That is, a rise of one-tenth foot in Lake Erie produces an increase in discharge of 2,200 cubic feet per second, causing at the same time a rise of 0.082 foot at foot of Squaw Island; while a lowering of 0.1 foot at foot of Squaw Island, Lake Erie elevation meanwhile remaining unchanged, would produce only 1,560 cubic feet per second increased flow. The latter condition is possible when the river regimen has been disturbed artificially. The International Bridge, a single track structure belonging to the Grand Trunk Railroad, crosses the river at Squaw Island and has eight river piers.

About three-quarters of a mile below Squaw Island the river is divided by Strawberry Island, and farther down by Grand Island. The channel east of Grand Island is known as the American or

Tonawanda Channel, while that west of Grand Island is called the Canadian or Chippawa Channel. From the point of division it is 12 miles by the Canadian and 16 miles by the American channel to the point of reuniting below Navy Island, about a mile above Welland River. From Squaw Island to Welland River the fall is 4.8 feet. The Chippawa Channel averages between one-half and three-fourths mile wide, and approximately 18 feet deep. The Tonawanda Channel for the first 7 miles is about one-third mile wide and 25 feet deep, and for the remainder of the way is about three-fourths mile wide and 10 feet deep. The current averages about 2 to 2½ feet per second in these two channels. The International boundary line follows the Chippawa Channel, close to Grand Island.

From 1 mile above to 1 mile below Welland River the Niagara River is roughly a mile wide, and averages 8 to 10 feet deep. This reach is known as the Chippawa-Grass Island Pool. Its average elevation is about 563 feet. It discharges over a natural rock barrier in a waterfall averaging 5 to 10 feet in height, and known as the first cascade. Hydraulically, the rock barrier is equivalent to a weir, and the first cascade is a free overfall. Diversions of water below the first cascade can have no effect on the river above the cascade, as for example the diversions on the Canadian side by the Toronto Power Co., Canadian Niagara Power Co., International Railway Co., and City Waterworks of Niagara Falls, Ontario. Diversions from Chippawa-Grass Island Pool are made on the United States side by the plants of the Niagara Falls Power Co. and Hydraulic Power Co., while on the Canadian side the diversion of the Ontario Power Co. is made from the lip of this pool.

The first cascade forms the upper portion of a series of cascades and rapids extending to the brink of the falls. This reach of river is about half a mile long and is divided longitudinally by Goat Island into the Canadian and American Rapids, the former being wide and the latter narrow. The drop from Welland River to brink of Horseshoe Falls is about 55 feet, while to the American Falls it is only 50 feet. Horseshoe Falls and American Falls are separated by Goat Island. The former is 3,000 feet long and 162 feet high; the latter is 1,000 feet long and 167 feet high.

From the foot of the falls the river flows in a gorge whose banks are 180 to 250 feet high for 6½ miles to Lewiston. At the latter locality the ground falls away very abruptly from an elevation of about 600 feet to an elevation of approximately 350 feet. From the foot of the falls for about 2 miles the river is roughly 800 feet wide at the water surface, and 100 to 192 feet or more deep. Its velocity is moderate, its surface generally smooth, and its drop in water surface from upper to lower end of the reach approximately 5 feet at mean stage. This reach is variously known as the Upper Gorge Pool, Pool Below the Falls, Maid-of-the-Mist Pool, etc. In this report it will be designated the Maid-of-the-Mist Pool. All of the present water-power developments discharge into the upstream half of this pool, whose average elevation is about 343 feet. A highway bridge known as the Upper Steel Arch Bridge spans the pool about 1,000 feet downstream from the American Falls.

Below the Maid-of-the-Mist Pool the next mile of the river is a wild, turbulent rapids called the Whirlpool Rapids, which dis-

charges into the Whirlpool. The water surface drops 48 feet from upper to lower pool. The average width at water surface in the rapids is 400 feet, and the average depth is roughly 30 feet. At the narrowest section the width is 320 feet and the mean depth 32 feet, while at the shallowest section the width is 410 feet and the mean depth 17 feet. The mean velocity is roughly 25 feet per second, the maximum velocity exceeding 38 feet per second. The upper end of the Whirlpool Rapids is crossed by two double track railway bridges, one known as the Michigan Central Cantilever Bridge, and the other the Grand Trunk Steel Arch Bridge. The latter is a double deck structure carrying a highway under the railroad tracks.

The Whirlpool is 1500 feet long, 1200 feet wide, and, according to the soundings of Dr. J. W. Spencer, 24 to 126 feet deep. Its average elevation is 292 feet. The level of the Whirlpool fluctuates through a greater range of stage than the level of any of the other pools, and the water surface is more disturbed.

The Lower Rapids extend from the Whirlpool, $3\frac{1}{2}$ miles to Lewiston. The total water surface drop in this distance is 46 feet. The rapids vary in width from 310 to 900 feet, and in depth from 40 to at least 150 feet. The slope is not as uniform as in the whirlpool, consisting in several steep pitches connected by sections of considerably less slope. About three-fourths mile below the Whirlpool is the beginning of the narrowest section, which extends downstream nearly half a mile. This portion of the rapids is abreast of a low lying piece of ground in the gorge on the Canadian side known as Niagara Glen or Foster Flats, and is sometimes called Foster Flats Rapids. It has a steep slope. At the lower end of the Lower Rapids there is a suspension bridge known as the Lewiston-Queenston Bridge.

From the suspension bridge to Lake Ontario is $7\frac{1}{2}$ miles, and the water surface drop is approximately one-half foot. This portion of the river is roughly one-half to one-third mile wide and 30 to 60 feet deep. The current is moderate. The banks are 50 to 100 feet high, becoming lower near the mouth of the river.

The general direction of the river is from south to north, although the portion above the Falls, frequently known as the Upper River, trends more nearly northwest, while the portion below the Falls, the Lower River, flows in general almost exactly north. Just above the falls the river is flowing almost due west and at the foot of the falls it turns more than a right angle, flowing a little east of north. The Canadian Falls is south of the American Falls. Another sharp right angled bend in the river occurs at the Whirlpool, where the direction of flow changes from northwest to northeast.

The Niagara River is navigable for boats of considerable size from Lake Erie to the Welland River and to docks behind Conners Island. It is navigable also from Lewiston and Queenston to Lake Ontario. In the Maid-of-the-Mist Pool two small steamers operate in summer time, carrying sightseers up close to the foot of the falls, but these boats do not attempt to navigate the rapids below.

The Niagara Route.—The Niagara River route, including a portage around the Falls and rapids, had been one of the main thoroughfares of the Indians from time immemorial, when, in the seventeenth century, it was discovered by the French explorers of the great natural inland waterway of the Great Lakes system. As early as 1678 the

French had a post which commanded the portage. The frontier passed into the control of the British in 1759. By both nations it was considered of vast importance because of this route between east and west, and its early growth was due to this fact. Toward the end of the eighteenth century, when the era of American canal building began, the idea of a canal to replace the portage was suggested several times, and it appears that a survey for a canal was made in 1784. In 1798 a company was incorporated to build such a canal, but nothing further was accomplished. Since that date but few years have passed without agitation for the construction of such a canal, and many surveys and estimates have been made.

Examinations and surveys ordered by Congress have been heretofore made and reports thereon published, as follows:

Niagara Ship Canal.	Congressional Documents.					Annual reports of Engineers.		Recommendation.
	Year.	House or Senate.	No.	Congress.	Session.	Year.	Pages.	
Five routes: depth, 10 feet; locks, 200 by 50 feet.	1836	House...	214	24th...	First....	.....	.....	Favorable.
Urging need for.....	1837	...do....	201	24th...	Second..	.....	.....	Do.
Five routes, depth 12 feet; locks, 275 by 45 feet.	1864	...do....	61	38th...	First....	.....	.....	None.
Six routes; depth, 14 feet; locks, 275 by 46 feet.	1868	H. Ex..	197	40th...	Second..	1868	271-287	Do.
Two routes; depth, 204 feet; locks 400 by 60 feet.	1889	.....	.....	.....	.....	1889	2434	Favorable.
Presentation favorable to above.	1892	House...	1023	52d...	First....	.....	.....	Do.
Presentation favorable to a canal.	1896	...do....	423	54th...	...do....	.....	.....	Do.
General preliminary examination and data.	1897	...do....	192	54th...	Second..	.....	.....	Do.
Four routes; depth 24 feet; locks 530 by 60 feet.	1897	...do....	86	55th...	First....	1897	3128-3237	Unfavorable.
La Salle-Lewiston route and Tonawanda-Olcott route; depth, 21 feet; locks, 600 by 60 feet; depth, 30 feet; locks, 740 by 80 feet.	1900	...do....	149	56th...	Second..	.....	.....	Favorable.

Surveys made under other auspices are enumerated as follows:

1784. First survey made for a canal around the Falls of Niagara; by private interests.

1798. Company chartered by the State of New York to construct a canal around Niagara Falls, capable of passing boats of 80 tons burden, said canal to be completed 10 years thereafter.

1808. Survey by James Geddes, under direction of surveyor general of the State of New York of route for a canal around the falls from Schlosser's to Lewiston.

1808. Secretary of the Treasury, under United States. Senate resolution submitted report of Niagara Ship Canal, Schlossers to Lewiston, via The Devils Hole.

1826. Survey by private individuals, with a view to obtaining a charter from the State of New York.

1853. Under charter granted by the State of New York, survey made by Charles B. Stuart and Edward W. Serrell for a canal between Tonawanda Creek and Lake Ontario. Proposed dimensions

of canal, 170 feet wide at top, 180 feet on the bottom and 14 feet depth of water, with locks 300 feet long and 70 feet wide in the chamber; estimated cost, shortest line, 8 miles long, with single locks, \$10,290,471.59; with double locks, \$13,169,569.69.

Plans of the United States Board of Engineers on Deep Waterways.—All previous preliminary examinations and surveys are regarded as superseded by the elaborate surveys made by the United State Board of Engineers on Deep Waterways, whose report, in two large volumes and a portfolio of plates, is that noted on the above tabulation as of 1900, House Doc. 149, 56th Cong., 2d sess. This is the most recent and also the most elaborate and complete survey and estimate. In the course of the present investigation a careful reconnaissance was made of both routes between Lake Erie and Lake Ontario, which were surveyed by the board and revision surveys of the La Salle-Lewiston route were made in sufficient detail to bring the information up to date. The Board of Engineers on Deep Waterways was appointed in 1897, "to make surveys and examinations (including estimate of cost) of deep waterways and the routes thereof between the Great Lakes and the Atlantic tide waters." The members were Maj. Charles W. Raymond, Corps of Engineers, United States Army, Alfred Noble, and George Y. Wisner. The work of the board was very extensive and of a very high grade. Under its direction nearly 500 square miles of topographic and hydrographic surveys were made, several hundred rock soundings taken, many miles of precise levels run, and many hydraulic measurements obtained. It also made extensive studies of traffic conditions, size of ships, speed of ships in canals, water supply to summit levels, and similar subjects.

The board investigated two routes between Lake Erie and Lake Ontario. One left the Niagara River at Tonawanda and entered Lake Ontario at Olcott, about 18 miles east of the mouth of the Niagara River. The other left the river at La Salle and entered the lower river at Lewiston, about six miles above its mouth. The board recommended the La Salle-Lewiston route as offering the most assistance to navigation and being also the cheapest.

The length of the proposed LaSalle-Lewiston canal is 9.16 miles. The vertical drop is 318.8 feet which is to be overcome by eight locks, arranged in one double flight of six and one double flight of two. Two sets of plans and estimates were made, one for a 21-foot channel and the other for a 30-foot channel. The principal dimensions of the two plans are as follows:

	21-foot channel.	30-foot channel.
Width of dredged channel in river.....	600 feet.....	600 feet.
Width of canal (bottom in rock section).....	240 feet.....	250 feet.
Length of locks, quoin to quoin.....	600 feet.....	740 feet.
Width of locks.....	60 feet.....	One set 60 feet, one set 80 feet.
Lift of locks, upper flight (each).....	40 feet.....	40 feet.
Lift of locks, lower flight (each).....	39.4 feet.....	39.4 feet.
Estimated cost.....	\$38,611,723.....	\$66,631,857.

These costs include a lock at Black Rock which has since been built. They also include the cost of regulating works at the head of the

river. The amount of water required to be diverted from Niagara River was not stated, but it probably was less than 1,000 cubic feet per second. The report is very exhaustive and represents the latest ideas as to what an Erie-Ontario Canal should be, except that the great size of ships now in use would require that the locks be made larger than recommended. The estimates of cost are, of course, quite obsolete because of the recent rise in prices.

The improvements to the Black Rock Canal, made since the report of the Deep Waterways Board, including construction of the new lock at Black Rock, have been described previously. Downstream from the lock the Niagara River has been improved for a distance of $2\frac{1}{2}$ miles to provide a channel 400 feet wide and 21 feet deep at low water datum, extending to deep water in the Tonawanda Channel, from which point the natural channel is of ample width and depth for 5 miles, or nearly to the head of the Tonawanda-Olcott route. Further authorized improvement will extend the 21 foot channel downstream $1\frac{1}{2}$ miles to the Tonawanda Iron & Steel Co. dock. The river thence to the head of the LaSalle-Lewiston route, $3\frac{1}{2}$ miles, has been improved to provide a channel 200 feet wide, and 10 feet deep at low water datum. Scattered boulders moved into the channel by ice have reduced the available depth to about 8 feet.

Further details of the work, plans, and estimates of the Deep Waterways Board are given in the following quotations from its report:

A careful reconnaissance made by the board in advance of the field work showed that only two of the routes from Lake Erie to Lake Ontario were worthy of investigation, viz: The route from the Niagara River at Tonawanda to Lake Ontario at Olcott, and from the river at LaSalle to Lewiston and thence through the Niagara River to the lake.

These were thoroughly investigated relative to volume and kind of material to be excavated, nature and dimensions of structures which will be needed, and character of foundation on which such structures will have to be erected.

The difficulties to be overcome on the two routes are practically the same and the real comparative merits of the waterways depend largely upon relative cost to construct and maintain them and the difference in time required by a type steamship to traverse the respective routes between points common to each.

* * *

The question has been raised as to the advisability of constructing locks, which will cost several million dollars, as close to the boundary between the United States and Canada as will be the case at the Lewiston escarpment; but when we consider the important lock and regulating structures which will be needed at the head of Niagara River, the deep channels already excavated in Canadian waters at the mouth of the Detroit River, and the locks and canals at Sault Ste. Marie, it is difficult to conceive, if the Lewiston location is objectionable for military reasons, why similar reasons should not have prevented the improvement of the entire upper lake system of waterways. * * *

In the very improbable event of a war with Great Britain, every large ship of war possessed by this country would be required on the high sea. Such vessels would be unnecessary on the lakes, since the greatest depth of the Canadian waterways is only 14 feet.

The survey of the Niagara Ship Canal was commenced in September, 1897, and, including borings, was completed in April, 1898. The work consisted in developing two routes from Lake Erie to Lake Ontario, one from Buffalo, via the Niagara River to Tonawanda, and thence by ship canal to Olcott, on Lake Ontario, and the other by the Niagara River to La Salle, near the lower end of Grand Island, and thence by ship canal to the Niagara River at Lewiston, from which place there is a good natural channel to Lake Ontario.

The topography of the country was determined with sufficient accuracy to develop contours of 2-foot intervals on the field maps, and borings were put down at such points as necessary to establish the profile of the rock surface

where above canal grade, along the line of the proposed waterway as finally located on the field maps. Fourteen diamond drill borings were afterwards put down along the location for these two lines to ascertain the character of material to be excavated, and the nature of foundations on which structures are to be founded.

Particular examination was made of the escarpment extending from above Lewiston to Lockport, with an average elevation of about 620 feet above mean tide at New York. A little west of Lockport a narrow ravine, known as the "Gulf" cuts through the escarpment, which has been generally regarded as the best location for locking down to the lower plateau.

Comparative estimates, based on accurate surveys, indicate that a better line can be located west of the "Gulf" in which the waterway can be constructed at less cost.

From the foot of the escarpment at Lockport the plateau, consisting of red shale, gradually falls toward Lake Ontario.

The top of the escarpment above Lewiston has practically the same elevation as at Lockport, but has a steeper incline toward Lake Ontario than the latter. The construction of a waterway by either route will involve the construction of locks having high lifts.

On the Lewiston route the Niagara River constitutes a first-class natural harbor for the Lake Ontario terminal, whereas for all the other routes artificial harbors will have to be constructed.

The La Salle-Lewiston route has fewer important railroad crossings than the Olcott route, and does not interfere with manufacturing and private enterprises to the extent that the latter does in the vicinity of Tonawanda.

From an engineering and financial point of view, and from the less danger of delays and accidents to navigation in the comparatively short reach of restricted waterway on the Lewiston line, it appears to be the preferable location on which to construct a ship canal.

The Tonawanda-Olcott route.—This route leaves the Niagara River at the head of Tonawanda Island, with an elevation of 565 feet above tide water at New York for low stage of the river, and continues at that level 13.2 miles to the head of the escarpment west of Lockport, where the ridge to be cut through has an elevation of 636 feet above tide water, or 71 feet above the water surface in the canal. From the top of the escarpment the line descends to Lake Ontario, 11.2 miles, with 2 single and 3 double locks of 40 feet lift each, one single lock with 30.5 feet lift, and 3 double locks each with 30 feet lift.

At a distance about 1 mile above Lake Ontario the line enters the gorge of Eighteen-mile Creek and follows it to the lake.

The proposed harbor at Olcott consists in widening Eighteen-mile Creek to the width of 400 feet from the last lock of the canal to the lake, and protecting the entrance by breakwaters, as shown on the maps. The lake in front of the canal entrance is shallow, with a shale rock bottom, which will have to be excavated for a width of 600 feet and for the required depth.

Between Niagara River and the escarpment at Lockport the rock, where above bottom grade of the waterway, is either limestone or Niagara shale, overlaid with silt, sand, gravel, clay, or hardpan.

From the head of the escarpment north, the excavation will be through limestone, sandstone and shale, and near Lake Ontario through soft red shale, overlaid with sand, gravel, clay, or hardpan.

La Salle-Lewiston Route.—This route starts in Niagara River at the same point as the Tonawanda-Olcott route, continues down the river to the head of Cayuga Island, and thence on a tangent (canal) with a low-water level of 563.5 feet to the escarpment above Lewiston. From the top of the escarpment the route passes down the bluff to the Niagara about one-half mile below Lewiston, with six double locks of 40 feet lift each and two double locks of 39.4 feet lift each. The fall of the river from the foot of Lock No. 9 to Lake Ontario (6 miles) is about 0.2 feet.

The elevation of the top of the ridge above Lewiston at the point of maximum cutting is 620 feet above tide water or 56.5 feet above the proposed low-water surface of the canal; and for a distance of 6 miles the prism of the waterway is entirely in rock.

From Tonawanda to La Salle, about 4 miles, rock composed of Salina shales is from 10 to 20 feet below river level, and from La Salle to the escarpment above Lewiston (7.5 miles) the excavation will be in Niagara limestone overlaid with clay, sand, and gravel.

The excavation for the six double locks down the escarpment about three-fourths mile will be through limestone, sandstone, and shales, and from the foot of this flight to Niagara River, shales covered with sand, gravel, clay, and boulders.

From the lower end of the canal to Lake Ontario (6 miles) the river is from 50 feet to 60 feet deep and forms one of the finest harbors on the lakes. The bar in Lake Ontario outside of the entrance to the river has a depth on its crest of 24 feet at standard low water, and is composed of sand and gravel.

Prism dimensions.—From a careful study of the dimensions of the St. Clair Flats Canal, the Suez Canal, the Manchester Canal, the Amsterdam Canal, the Kiel Canals, and the speed which steamships can maintain in these respective waterways, it is the opinion of the board that the cross section of the canal prism should be made such that a speed of 8 miles per hour can be maintained on tangents without danger to passing ships or damage to the canal banks.

Referring to the discussion of the speed of ships in the proposed deep waterway, in Appendix No. 4, it will be noted that for the type of vessels best adapted for the economical transportation of the lake traffic the cross section of canal prism necessary to permit a speed of 8 miles per hour is about 5,500 square feet for a 21-foot waterway and 8,000 square feet for a 30-foot waterway.¹

The dimensions of lock structures which will best subserve the traffic of the waterway and the design of the lock gates best adapted for operating the locks have been investigated under the direction of the board by specialists in such construction, the results of which are fully discussed in Appendix Nos. 1 and 2.

The single locks, which have been designed for a 30-foot waterway, are to be 740 feet long, 80 feet wide, and have lifts to conform with the present development of water power on the routes. Where flights of locks are necessary, a duplicate set is provided, having a width of 60 feet. For a 21-foot waterway the locks, whether single or double, are to be 600 feet long, 60 feet wide, and have lifts the same as in the 30-foot waterway. Consideration has been given to the advisability of making the locks of the 21-foot waterway 80 feet wide, for the purpose of floating large ships, light, from the lake shipyards to the seaboard.

Proposed ship canal.—In this report the matter of a ship canal between Lake Erie and Lake Ontario is treated at considerable length for two reasons: First, to comply with instructions contained in department letters dated August 4, 1916, E. D. 42608, September 29, 1916, E. D. 101152, and April 28, 1917, E. D. 106256, which cover the preliminary examination on "Waterway or ship channel along the most practicable route between Lake Erie and Lake Ontario of sufficient capacity to admit the largest vessels now in use on the Great Lakes," ordered by Congress in the river and harbor act of July 27, 1916, which examination and report were held by the department to be superseded by and included in the investigation reported herein; and second, to comply with department instructions that such a canal should be treated in the present report with special reference to the practicability and advisability of making it a combined power and ship canal.

A summary of the estimates prepared is given in section (f) of this report, where the project is described in considerable detail in connection with other projects for the development of water power at Niagara Falls. For a ship canal without power development the estimated costs are as follows:

¹ The figures show, for 21-foot channel: Rock section, bottom width 240 feet. Side slopes, 10 on 1, area 5,040 square feet. Earth section, bottom width 215 feet. Side slopes, 1 on 2, area 5,497 square feet.

For 30-foot channel: Rock section, bottom width 250 feet. Side slopes, 10 on 1, area 7,500 square feet. Earth section, bottom width 208 feet. Side slopes 1 on 2; area: 7,990 square feet.

Prism.	Locks.	Cost.
200 feet wide, 25 feet deep.....	650 feet long, 70 feet wide, 25 feet deep.....	\$120,000,000
200 feet wide, 30 feet deep.....	800 feet long, 80 feet wide, 30 feet deep.....	135,000,000
300 feet wide, 30 feet deep.....	800 feet long, 80 feet wide, 30 feet deep.....	155,652,000

It is important to note that the new Welland ship canal, only a few miles distant, which is now partially completed, and which no doubt will be opened to navigation long before a canal in the United States could be constructed, will be able to care for all the traffic likely to exist between Lake Erie and Lake Ontario for many years to come, and that accordingly there is no necessity for an additional canal. Moreover it should be borne in mind that communication between Lake Ontario and the seaboard is still limited by the St. Lawrence canals and shallows in the St. Lawrence River described previously.

The present commerce through the Welland Canal has been stated, and also that through the St. Marys River. A comparison shows how very small a part of the Great Lakes commerce now uses the Welland route. The extensive lake freight commerce between the terminal harbors on Lakes Superior, Michigan, and Huron to harbors on Lake Erie amounts, so far as determinable from the commercial statistics and vessel passages through the St. Marys Falls canals and Detroit River, to at least 95 per cent of the total, which aggregated over 100,000,000 short tons in 1916, leaving not over 5 per cent for the Welland Canal-Lake Ontario commerce. The latter commerce is represented in Table No. 10, compiled from the report of the Department of Railways and Canals, Canada, for the season of 1914:

TABLE No. 10.—*Freight moved through Welland Canal, 1914.*

	Tons.
Agricultural products.....	2,116,378
Forest products.....	360,434
Coal.....	949,306
Miscellaneous.....	484,851
	3,860,969
Through freight eastward.....	2,936,740
Carried by Canadian vessels.....	2,936,740
East and west to United States ports.....	509,079
Carried by United States vessels.....	788,359

As shown by the above tabulation, the freight movement is principally through freight eastward. It consists largely of grain from upper Lake ports, notably Fort William, in Canada, on Lake Superior, and from Milwaukee and Chicago, shipped for transfer to sea-going vessels at Montreal. The coal shipment is from United States ports on Lake Erie to Canada. The "forest-products" shipment is lumber from upper Lake United States and Canadian lumber ports to Lake Ontario and St. Lawrence River United States and Canadian ports, and pulp wood and wood pulp from upper Lake ports to United States ports on Lake Ontario and from the lower St. Lawrence River and Saguenay River ports to United States ports on Lake Erie. The latter and general merchandise constitute the principal freight movement westward through the Welland Canal; but it is not extensive, and is necessarily carried on by Lake vessels of not over 14-foot draft navigating the St. Lawrence River Canals as well as the Welland.

It will be noted that the amount of freight "east and west to United States ports" is small—about 500,000 tons. About one-quarter of this is grain and lumber eastward to Ogdensburg, N. Y., except about one-twentieth to Oswego, N. Y., and the other three-quarters is the pulp wood above mentioned and general merchandise (railroad freight) from Ogdensburg westward to Chicago and Milwaukee. The railroad freight movement (70,000 to 100,000 tons) was, however, discontinued in 1915 on the abolishment of the Rutland Railroad line of freight vessels.

There is no passenger service through the Welland Canal, and the number of yachts and motor boats traversing it is small. The United States lighthouse tender for the tenth district and the United States engineer inspection vessel, Buffalo district, use the canal for several trips per year to and from Lake Ontario.

To summarize, the present commerce between Lakes Erie and Ontario may be fairly regarded as not exceeding 4,000,000 freight tons per annum, of which not over 10 per cent is United States commerce, coastwise or foreign.

A waterway or channel to admit the largest vessels now in use on the Great Lakes involves the dimension of depth or draft, as well as of length and breadth over all. The question of draft involves vessels about as represented in the existing lake fleet whose possible load-draft is greater than 21 feet. The percentage of such vessels in the lake fleet of about 700 large vessels, length 200 to 600 feet, may be fairly approximated as follows:

Load draft 20 to 21 feet, 10 per cent.

Load draft 21 to 22 feet, 25 per cent.

Load draft 23 feet, 11 per cent.

Load draft 24 feet, 12 per cent.

These percentages are derived from molded depth of vessels as given in the official register of vessels, on the assumption that for vessels of the general lake type, the molded depth is practically equivalent to the sum of the draft and freeboard. There appear to be no regulations governing the amount of freeboard required on vessels on the Great Lakes, but considering the amount required on ocean-going vessels and the freeboard of known lake vessels, it has been assumed that such vessels with a molded depth of 28 feet or less should have 6 feet of freeboard, those from 28 to 31 should have 7 feet, and those greater than 31 should have 8 feet. The largest vessel as to draft is therefore taken to be as of a possible 24-foot draft.

It is to be noted, however, that owing to existing conditions of channels and basins on the Great Lakes, freight tonnage is actually carried in vessels as indicated by the classification of vessels passing through the St. Marys Falls Canals, about as follows:

Vessels, net registered tonnage:	Percentage of the freight.
Under 1,000	1
1,000 to 2,000	6
2,000 to 3,000	9
3,000 to 4,000	28
4,000 to 5,000	27
5,000 to 6,000	25
6,000 and over	4
	<hr/> 100

The draft of vessels of 2,000 tons and over, carrying 84 per cent of the freight was 18 to 21 feet, and those vessels are comprised in the class of vessels that can be loaded to deeper draft as noted in the table above. They carry nearly all of the bulk freight, while the remainder thereof and the merchandise freight is carried in package freighters and smaller vessels whose draft can not be economically increased.

The question of length and breadth over all is taken as that of the largest lake freight vessel, viz, length 625 feet and breadth 64.2 feet, which excludes only a few side-wheel passenger steamers of breadth up to the maximum of 100 feet over guards. Of a total of 150 vessels over 500 feet long and over 50 feet beam over all, there were, in 1916, 34 vessels 600 to 625 feet in length and 58 to 64.2 feet in breadth.

For further treatment of the LaSalle-Lewiston Ship Canal, and consideration of correlative power development, reference is made to section (f) of this report.

9. PROPOSED CANALS, LAKE ONTARIO TO HUDSON RIVER.

Four water routes from Lake Ontario to the sea have in the past received consideration. One of these is the natural route by way of the St. Lawrence River. The other three are by way of the Hudson River, which is reached in one case by way of the St. Lawrence to Lake St. Louis, artificial canal from there to Richelieu River, up Richelieu River to Lake Champlain, and on to the Hudson by Lake Champlain and an artificial canal; in another case by the St. Lawrence to Lake St. Francis, then by artificial canal to Lake Champlain, and on to the Hudson as before; and in the third case by way of the Oswego, Oneida and Mohawk Rivers. Only the last route lies entirely in United States territory. All four routes are described in the report of the United States Deep Waterways Commission published in 1897 as House of Representatives Document No. 192 (54th Cong., 2d sess.) and are shown in plate 2 of that report which is here reproduced on plate No. 12.

The route from the ocean to Lake Ontario by way of the Hudson River, Mohawk River, Oneida Lake, and Oswego River is one of the early water routes that has been used since the first settlements. It formed the usual connection between New York and the Lakes before the land route by way of Rochester and Buffalo was developed. A proposal to improve it by locks at Little Falls was made by the royal Governor of New York in 1768. In 1791 the first surveys for improving this route were made and some work was done on the eastern part during the following years. During the construction of the Erie Canal there was much agitation in favor of connecting it with Lake Ontario by means of the Oswego River. This was finally successful, and in 1829 the "Oswego Canal" was opened. Since that time it has formed part of the New York State canal system.

The Deep Waterways Board considered two routes from Lake Ontario to the sea, one by way of the St. Lawrence River to Lake St. Francis, Lake St. Francis to Lake Champlain by artificial canal, and on down Lake Champlain and the Hudson River; the other by the Oswego, the Mohawk and the Hudson Rivers. It recommended the latter as the more desirable. The length of this route from Lake

Ontario at Oswego to the Hudson River at the mouth of Normans Kill is 172.9 miles. The line starts $1\frac{1}{2}$ miles west of the mouth of the Oswego River and runs south about 6 miles to lock No. 4, where it enters the river. It follows the river 5 miles to lock No. 5, and then goes across the divide 15 miles to Oneida Lake. After traversing the length of the lake, 21 miles, it follows the line of Wood Creek to Rome, a distance of 13 miles. Thence it continues 89 miles down the Mohawk River to a point just above Schenectady, where the line leaves the Mohawk and cuts across the divide, a distance of 11 miles to Normans Kill and follows the kill for 13 miles to the Hudson River. The standard sections in rock are 240 feet wide for the 21-foot channel and 250 feet for the 30-foot. The standard earth section has side slopes of 2 horizontal to 1 vertical, with berms 10 feet wide situated 5 feet above and 5 feet below the water surface. There is slope paving between the berms. The bottom width is 215 feet for the 21-foot channel and 203 feet for the 30-foot. In Oneida Lake the width is 600 feet and in the Mohawk River below Herkimer it varies from 203 to 460 feet.

There are 29 locks, the lift of each varying from 3 to 42.8 feet at low water. The total lockage is 512.6 feet. Fourteen of these locks are arranged in five flights of 2, 2, 2, 3, and 5 locks, respectively. These locks are all double, the others are single. For the 21-foot channel all locks are 600 feet long and 60 feet wide. For the 30-foot channel they are 740 feet long, the width being 80 feet for single locks, and 80 feet and 60 feet, respectively, for the two chambers of double locks.

There is a summit level with a length of 72 miles extending from Lock No. 7, west of Brewerton eastward to Lock No. 8, near Frankfort, including Oneida Lake, which is used as a reservoir. Some difficulty was encountered in finding a sufficient water supply for this summit level, but it was finally obtained by diverting part of the Salmon River through a feeder. It was estimated that the summit level would require a supply of about 1,100 cubic feet per second, of which about two-thirds would be water which would normally flow into Lake Ontario. As this water would eventually be divided about equally between the canal east and west of the summit, it follows that some water would be permanently diverted from the Great Lakes drainage. The route through the Mohawk Valley below Frankfort is of the slack water type, to be maintained by 8 large dams.

These plans were very carefully worked out by the Deep Waterways Board and were based on extensive and carefully executed surveys and studies. The building of the New York State Barge Canal system along this route has made the construction of this ship canal as planned impossible, and has rendered very difficult the proposition of providing any ship canal along this route, especially in respect to providing an adequate water supply for the summit level.

10. OTHER PRESENT OR PROPOSED CANALS DIVERTING WATER FROM THE GREAT LAKES OR THEIR TRIBUTARIES.

The Fox River Canal.—This is a canal in Wisconsin between the Fox River, a tributary of Lake Michigan, and the Wisconsin River,

a tributary of the Mississippi. It is 2 miles long and affords a passage for boats 137 feet long, 34 feet wide, with a draft of 3 feet. The attempt to maintain the Wisconsin as a navigable stream was abandoned in 1887, and the traffic through the canal is very small. In the improved Fox River there is slack water navigation with a draft of 6 feet, except for shoaling, from Green Bay to Montello and of 4 feet from there to the canal. The canal is supplied with water from the Wisconsin River, which is about 5 feet higher than the Fox; hence there is no diversion of water from the Great Lakes system by the canal; on the contrary, a very small addition of water is received from the Mississippi system. The work of improving this waterway from Lake Michigan to the Mississippi was undertaken in 1846 by the State of Wisconsin, which was assisted by a grant from the National Government of 691,200 acres of land lying along the route. In 1853 the land and works were sold to an improvement company, and in 1872 the Federal Government assumed control of the waterway by purchase.

The Trent Canal.—This is the name applied to a series of natural and artificial waterways from Trenton, Ontario, at the mouth of the Trent River, on the Bay of Quinte, Lake Ontario, to Honey Harbor, about 10 miles north of Midland, on Georgian Bay, Lake Huron. This chain of lakes and rivers does not, in its present condition, form a connected route for navigation, though various parts have a considerable local use. By works now building this will become a through route from Lake Ontario to Lake Huron. The route lies in the Trent River, Rice Lake, and Otonabee River, and Clear, Stony, Lovesick, Deer, Buckhorn, Chemong, Pigeon, Sturgeon, and Cameron Lakes to Lake Balsam, which is the summit level, and from Lake Balsam by a canal and the Talbot River to Lake Simcoe. From Lake Simcoe the route is through Lake Couchiching and down the Severn River to Gloucester Pool, leaving Gloucester Pool by the Go-Home Lakes and South Honey Harbor and entering Georgian Bay at Skylark Rock between the islands of Beausoleil and Minnicoganashene. Another passage between Gloucester Pool and Georgian Bay is provided by a small lock at Port Severn. A branch of the main route extends from Sturgeon Lake south along the Scugog River to the town of Lindsay, and thence through Lake Scugog to Port Perry. The total length of the main route is 245 miles, and of the Scugog Branch 30 miles. Another branch along the Holland River from Lake Simcoe to Newmarket, a distance of 12 miles, formed part of the original plan, but work on it was discontinued in 1911. There are 46 locks on the main route and one at Lindsay on the Scugog branch and a small one at Port Severn. Two of these locks are of the very unusual "hydraulic lift" type, the one at Peterborough being noted for its great lift of 65 feet.

The 18 locks between Lake Ontario and Rice Lake are 175 feet long, 33 feet wide (available dimensions 150 by 30 feet) and have a depth of 8 feet 4 inches on the sills. The depth in the canal reaches is 9 feet. This work is not yet completed and only a portion of the route is navigable. From River Lake to Lake Couchiching the limiting dimensions of the locks are 134 feet by 33 feet (available 110 feet by 30 feet) with depths of 6 feet on the sills. This section is open to navigation with a limiting depth of 6 feet. The Scugog branch

also is open to 6-foot navigation. Its lock is 142 by 33 feet. The section from Lake Couchiching to Georgian Bay is under construction. The locks are said to be "large," probably the same as on the Rice Lake division, and have a depth of 8 feet 4 inches on the sills. The lock at Port Severn is 100 feet by 25 feet with 6-foot depth.

The summit level at Balsam Lake has a low-water elevation of 840 which is 597 feet above Lake Ontario and 262 above Lake Huron. Nothing is known about the water supply to this summit level. It probably amounts to only a few hundred cubic feet per second. Presumably part of this is diverted from the Huron watershed to the Ontario or vice versa, thus decreasing or increasing the flow of the St. Clair, Detroit, and Niagara Rivers by a trifling amount. The matter is of no practical importance in any study of lake levels or allied subjects.

This canal was begun by the British Government in 1837, but work was soon suspended. At various times since then local improvements have been made. In 1907 the project from the Bay of Quinte to Rice Lake was adopted by the Dominion Government and construction was started in the same year. The cost of construction up to March 31, 1916, was \$15,626,295. In 1914 the vessel passages were 3,647 and the tons of freight carried were 67,715. In 1915 the figures were 3,433 and 49,904, respectively.

The Rideau Canal.—The Rideau Canal or "Rideau navigation" connects the Ottawa River at Ottawa, Ontario, with the eastern end of Lake Ontario at Kingston, Ontario, by means of a chain of rivers, lakes, and canals 126½ miles in length. From Ottawa the route ascends the Rideau River 63 miles to Rideau Lake, passing by a lock at the narrows into Upper Rideau Lake, which forms the summit level. It then descends through Mud, Clear, Indian, Mosquito, Opinicon, Sand, Whitefish and Cranberry Lakes to the Cataraqui River and 29 miles down this river to Kingston. There is a branch line 7 miles from Beveridges Bay on Rideau Lake, to the town of Perth. From Ottawa to the summit level there are 33 locks with a total rise of 292½ feet. From the summit to Kingston there are 14 locks with a total fall of 165½ feet. The low-water elevations are: Ottawa River at Ottawa, 127.4; Summit level, Upper Rideau Lake, 408; Lake Ontario at Kingston, 243. On the Perth branch there are two locks with a total lift of 26 feet. The locks are 134 feet long, 33 feet wide, with a depth of 5 feet on the sills. The canal sections have a navigable depth of 5 feet. The bottom width is 54 feet in rock and 60 feet in earth. The total cost of this canal up to March 31, 1916, was \$4,657,668. In 1914 the number of vessel passages was 2,635 and the tons of freight carried were 151,739. In 1915 the figures were 2,076 passages and 120,781 tons. The water supply for this canal comes from the Wolf Lake system, the Tag River, and the Mud Lake system. It can not exceed a few hundred cubic feet per second. A certain amount of water is probably diverted from the Lake Ontario drainage to the Ottawa or vice versa. The amount is so small that it can have no practical effect upon the hydraulic problems of the St. Lawrence River.

It is an interesting historical point that this canal was built as a military measure. During the War of 1812 the only good com-

munication between Montreal and Lake Ontario was through the St. Lawrence River, and this was often interrupted by the Americans who held the south bank of that river for about 100 miles. In 1815 a captain of the Royal Engineers recommended the construction of a military canal by the Rideau route which would avoid this difficulty. Construction was commenced in 1826 and finished in 1832. The canal was built by the British, not the Canadian Government, under the supervision of the Royal Engineers, but was turned over to the Dominion in 1856.

Abandoned New York State canals.—Three small canals in New York State formerly had some little effect upon the water supply of the Great Lakes. These were the Chenango, Chemung, and Genesee Valley Canals. The first connected the Erie Canal at Utica with the Susquehanna River at Binghamton with a length of 97 miles. The second connected Seneca Lake with the Chemung River, a branch of the Susquehanna, at Elmira, with a length of 23 miles. The third connected the Erie Canal at Rochester with the Allegheny River at Olean with a length of 107 miles. The canals were all of the same size. Their locks were 90 feet by 15 feet horizontally, by 4 feet depth; the canal prism was 26 feet wide on the bottom, 42 feet on the water surface, and 4 feet deep; they accommodated boats of 75 tons capacity. These canals have all been abandoned. Small sections which serve as feeders to the present New York State canals have been mentioned previously in this report.

Shenango Canal.—The construction of this canal was authorized in 1836 and completed in 1844. The route extended from the city of Erie, on Lake Erie, to New Castle, on the Shenango River, where it connected with the Beaver Canal, extending to Beaver, Pa., on the Ohio River. Its length was 106 miles, of which 96 miles was in artificial canal and 10 miles was slack water navigation in an improved river. The entire route was in Pennsylvania. The canal was 30 feet wide on the bottom, 54 feet on the water surface, and 4 feet deep. It had 112 locks with a total rise and fall of 797½ feet. The locks were 80 feet by 15 feet, and 4 feet deep. The canal afforded navigation for boats of 65 tons cargo capacity. The total cost of construction was over \$4,000,000. A branch canal to the east connected with the Allegheny River, and one to the west with the Ohio & Erie Canal. The Shenango Canal was abandoned in 1870. As it connected the Ohio Basin with the Great Lakes, it must have caused some slight diversion of water one way or the other.

Ohio & Erie Canal.—This canal runs from Portsmouth, on the Ohio River, to Cleveland, on Lake Erie, a distance of 309 miles. Construction was commenced in 1825 and finished in 1833. The prism is 26 feet wide on the bottom, and 40 feet on the water surface, and the depth is 4 feet. There were originally 161 locks, with a total rise and fall of a little over 1,200 feet. The locks were 90 feet by 15 feet, and 4 feet deep. The maximum sized boat which could navigate the canal was of 90 tons capacity. The cost of construction was \$4,695,204. The summit level diverted a small amount of water from the Tuscarawas River, a tributary of the Ohio, into Lake Erie.

This canal has been abandoned.

Miami & Erie Canal.—The Miami & Erie Canal runs from Cincinnati, on the Ohio River, to Toledo, on Lake Erie, by way of

Dayton and Defiance. Its length is 244 miles. It was commenced in 1825 and completed in 1845. The dimensions of locks and prism on the three divisions are as follows:

Division.	Width at surface.	Width on bottom.	Depth of prism.	Length of lock.	Width of lock.	Depth on sill.
Cincinnati-Dayton.....	40	26	4	87	15	4
Dayton-Defiance.....	50	36	5	.....	15	5
Defiance-Toledo.....	60	46	6	90	15	6

There are 105 locks, and the total rise and fall is 907 feet. The cost of construction was \$5,920,200. The water supply for the summit level was obtained chiefly from the headwaters of the Miami River and a small quantity was probably diverted into the Mississippi basin.

This canal has been abandoned.

It is interesting to note that altogether the Federal Government donated to the State of Ohio 1,230,522 acres of land in aid of canal construction.

Proposed Lake Erie & Ohio River Canal.—This is a proposed barge canal connecting the Ohio River at the mouth of the Beaver River with Lake Erie either at Indian Creek or Ashtabula. The route lies partly in Pennsylvania and partly in Ohio. Surveys for such a canal were made in 1889 by the State of Pennsylvania, in 1894 by the Pittsburgh Chamber of Commerce, and in 1905 by the Merchants and Manufacturers' Association of Pittsburgh. As a result of this last investigation the Lake Erie & Ohio River Ship Canal Co. was organized to build and operate the waterway. This company spent \$60,000 for surveys and studies and reported favorably on the project, but owing to the financial panic of 1907, was unable to secure the funds for its construction. In 1911 the National Waterways Commission studied the project. It reported the project both feasible and desirable and recommended that if local interests would build the canal the Federal Government should construct the harbor at its Lake Erie end and deepen the Ohio River from Beaver River to Pittsburgh. About this time the Lake Erie & Ohio River Canal Association was formed for the purpose of constructing the canal with public funds. These funds were to be obtained from the counties bordering on the canal and the waterways connecting with it and from the States of Pennsylvania, Ohio, and West Virginia and the National Government. The association obtained from the three States the legislation necessary to enable it to proceed. The project was interrupted by the war, and it is not known what action, if any, is now proposed.

The following description of the proposed canal is taken from the 1917 report of the Lake Erie & Ohio River Canal Board of the State of Pennsylvania:

The route of the canal should be as follows: Beginning at the mouth of the Beaver River in the State of Pennsylvania and running thence in the channel of said river 20.7 miles to the junction of the Mahoning and Shenango Rivers; thence in the channel of the Mahoning River 29.4 miles to Niles, Ohio, with only such departures from said river channels as are necessary to eliminate unnavigable curves; thence following generally the valley of Mosquito Creek about 8.4 miles to a point in Trumbull County, approximately 2.5 miles south-

west of the village of Cortland, Ohio, which point is the southerly limit of the summit level of the proposed canal; thence in a course almost due north across said summit level a distance of 27.3 miles to a point about 2 miles east of Rock Creek, Ohio, which point is the northern limit of the summit level; thence by the valleys of Grand River and Indian Creek about 15.7 miles to a point at or near the mouth of Indian Creek, on Lake Erie, approximately $6\frac{1}{4}$ miles west of Ashtabula, making the total length of the route $101\frac{1}{4}$ miles.

On this route the elevation to be ascended from the mouth of the Beaver River to the summit level is 232 feet and the descent from the summit level to the lake 327 feet.

The number of locks required will be 26, with lifts of from 10 to 30 feet.

The canal should be not less than 12 feet deep, with locks 56 feet in width by 400 feet in length, with depth of 12 feet over miter sills. The bottom width of the canal should be not less than 140 feet and its surface not less than 188 feet.

The cost of this canal at prices prevailing in 1914-15 is estimated to be \$85,000,000 and its capacity 38,000,000 tons per annum. This estimate of cost does not include branches to New Castle, Pa., and Warren, Ohio, each of which will cost, roughly, \$3,500,000.

The proposed canal connects the two largest inland waterways in the United States and traverses a district through which there is a tonnage movement greater than that of any other district of equal area in the world.

The water supply for the summit level of the proposed canal comes from the headwaters of French Creek, Shenango River, and Mosquito Creek, tributaries of the Ohio River; and from the head waters of Mill Creek and the Ashtabula River, tributaries of Lake Erie. The total supply is estimated at 382 cubic feet per second, or 667 cubic feet per second if the canal be provided with double locks. As this small amount is to be drawn partly from the Erie drainage, but largely from the Ohio drainage, and is to be discharged from the summit level about equally in each direction, it is evident that the resultant effect would be a slight additional supply of water to the Great Lakes system rather than a diversion therefrom.

Proposed Lake Erie-Lake Michigan Canal.—A canal to connect the southern end of Lake Michigan with the western end of Lake Erie has lately been proposed. This canal would shorten the water route from Chicago to the East by about 400 miles. In 1911 and 1912 the National Waterways Commission investigated this route. It recommended that a ship canal should not be considered, but thought that a barge canal along this route might be justified, and urged that the Corps of Engineers make a survey and careful study of a barge-canal project. A special board of engineer officers was appointed. This board reported in 1917 (see H. Doc. No. 343, 65th Cong., 1st sess.). The essential points of the report are as follows:

Two types of canal are discussed: The first, a ship canal with a depth of 24 feet; the second, a barge canal with a depth not to exceed 16 feet. The principal argument advanced in favor of the former is that a ship canal would be necessary to compete with the Georgian Bay Ship Canal, which is contemplated by Canada, and that it would allow the ordinary lake steamers to pass through without breaking bulk. In support of the barge canal, it is urged that a considerable portion of the traffic of the canal would consist of through freight between Chicago and New York, and that the dimensions of the waterway need not be materially greater than those of the New York State Barge Canal. The only advantage a ship canal would offer for freight between Chicago and New York would be the saving in time over the present route through the Straits of Mackinac. An analysis of the relative time of the route by the canal and by the Straits of Mackinac indicates a saving in favor of the canal for a lake speed of less than 11 miles per hour, but a loss if the lake speed were increased to 11 miles or more. Considering the relative merits of the ship and barge canals, the special board is of opinion that the former does not offer sufficient advantages to justify its selection.

The dimensions contemplated for the barge canal conform generally to those of the New York State canal, and for the channel are: Depth, 12 feet; over-head clearance, 18 feet; bottom width, 110 feet, increasing in open water and at bends; and for the locks, width, 45 feet; length between quoins, 338 feet. These dimensions are considered suitable for a vessel 300 feet long, 42 feet beam, and 10 feet draft.

A number of routes were covered by reconnaissance, and of these two were selected for survey. Both follow the Maumee from Toledo to Fort Wayne, whence there is a northern and a southern route to Lake Michigan. The Maumee River is canalized by locks and fixed dams. The elevation of the pool at Fort Wayne is 740 feet above sea level, 170 feet above Lake Erie. The length of this section is 109.5 miles.

The northern route is through Elkhart and South Bend to Michigan City. Its summit is 250 feet above Lake Erie; its length, 60.7 miles, and it has 14 locks and 7 guard gates. The total length of the northern route from Toledo to Michigan City is 242.5 miles; to Calumet Harbor, 275 miles; and to Chicago Harbor, 280.5 miles. The total lift above Lake Erie is 250 feet, and above Lake Michigan, 241 feet, and there are 23 locks and 14 guard gates on the entire route.

The southern route is by way of Huntington and Rochester to the neighborhood of Gary, thence via Calumet River and Indiana Harbor to Calumet Harbor. Its length is 82.7 miles, its summit, 765 feet above sea level, and it has 9 locks and 10 guard gates. The total length of this route from Toledo to Calumet Harbor is 269.5 miles, and to Chicago Harbor, 281.5. The total lift above Lake Erie is 195 feet and above Lake Michigan, 186 feet, and there are 18 locks and 17 guard gates. From an engineering standpoint either route is feasible, but there are fewer difficulties to be overcome on the northern than on the southern route, and the water supply system of the northern route is superior. Navigation conditions would be practically the same by either route. A larger population and more manufacturing interests would be served by the northern route, and for various reasons given the special board prefers this route.

It is estimated that with the assistance of flash boards, reservoirs, and steam auxiliary it may be practicable to develop a daily output of 16,069 horsepower from the dams of the Maumee, provided all the power be developed as a whole, and that this might eventually produce a revenue of \$96,500.

Estimates of cost are given as follows:

Route.	Single locks.	Double locks.
Northern.....	\$125,078,248	\$147,042,764
Southern.....	135,956,195	148,829,893

These figures include right of way, water power, damages, bridges, and terminals at intermediate points, but not at Toledo and Chicago. Operation and maintenance for the northern route are estimated at \$2,026,173 for single locks and \$2,205,642 for double locks, and, for the southern route, \$2,089,343 for single locks and \$2,232,447 for double locks.

The special board's analysis of traffic possibilities and the economic aspect of the project lead to the conclusion that its value should be based primarily on its use as a part of a through waterway between the Atlantic seaboard and the region of the Great Lakes and Upper Mississippi Valley, although it might reasonably be expected that it would confer benefits in the way of local traffic. The special board finds that so far as cost of carriage and time of transit are concerned the existing through water route from Chicago to New York via the Straits of Mackinac is preferable to the proposed waterway, even if the large governmental expenditure be not considered. It is of opinion that the proposed waterway could not offer rates which would be economically sound and at the same time sufficiently low to attract the traffic.

Comparing the waterway with rail the special board finds that it would be far more expensive than a railroad of equal capacity, and that it would have the serious disadvantage of being closed to traffic several months of each year by ice. The special board is of opinion that as a general principle no expenditure for additional transportation facilities is warranted if equal or better

and adequate facilities already exist or might have been otherwise provided at less cost, and in the present case the existing route affords a means of cheaper transportation of far greater capacity. The special board finds that the possible returns to the United States from the water power that might be developed would be relatively so small that they would have little weight in determining the advisability of constructing the waterway. In conclusion the special board expresses the opinion that a waterway on either of the proposed routes promises no advantages over present means of transportation at all commensurate with its cost and that the construction of such a waterway should not be undertaken by the United States. One member suggests further study looking toward the needs of the future.

The required water supply was estimated not to exceed 1,200 cubic feet per second for double locks and maximum traffic possible. This supply would come mostly from the tributaries of Lake Michigan and Lake Erie and would result in a slight transfer of water from one basin to the other. A small amount would probably be received from the tributaries of the Mississippi River, and this would result in a gain to the Great Lakes Basin. The water supply details were not worked out fully.

Proposed Georgian Bay Ship Canal.—The Georgian Bay Ship Canal project is a very large and ambitious scheme. The route by the Ottawa River and Lake Nipissing to Georgian Bay was first used by Champlain in 1615. For two centuries thereafter it was an important route of the western fur trade. The improvement of navigation along this line began with the building of a small lock at Vaudreuil near the eastern end in 1816. Two Ottawa River canals, namely, the Carillon and Grenville, and the Rideau Canal from Ottawa to Kingston were known as the Military Canal. Construction of them was commenced in 1827 and finished in 1833. The St. Anne de Bellevue Lock was opened in 1841. Since then the Ottawa locks have been enlarged at various times. In 1894 the Montreal, Ottawa & Georgian Bay Canal Co. was incorporated to build a canal with a depth of at least 9 feet from Georgian Bay to Montreal. Its charter as amended in 1908 provided that construction should be started in 1910 and completed in 1916. As far as is known, no work of importance has been done by this company.

In 1904 the Dominion parliament appropriated \$250,000 for making a detailed survey of this route. The board reported in 1909 that the canal could be built from Montreal Harbor through the Ottawa River, Mattawa River, Lake Nipissing, and the French River to French River Village, on Georgian Bay for \$100,000,000, and in 10 years' time. Annual maintenance was estimated at \$900,000. The canal would be 440 miles long and would be large enough for the largest lake freighters. The summit level was to be at elevation 677, which is 659 feet above Montreal harbor, 98 feet above Georgian Bay, and 29 feet above Lake Nipissing. The proposed canal has 23 locks east of the summit and 4 locks west, 27 locks in all. The locks are 650 feet long and 65 feet wide, with 22 feet clear depth on the sill. In the river sections slack water is secured by 18 dams. The route has 28 miles of canal with a bottom width of 200 feet, 66 miles of dredged channel with a bottom width of 300 feet and 346 miles of river and lake waterway with widths varying from 300 feet up to half a mile.

The water supply for the summit level is all obtained from streams naturally tributary to the Ottawa River. Hence a certain amount of

water would be diverted from this river into Georgian Bay. The effect on the Great Lakes and their connecting rivers would be insignificant, as the total quantity of water estimated to be required by the summit level is less than 600 cubic feet per second.

For several years after this report was published there was much controversy between the advocates of the Georgian Bay Canal and those who favored enlarging the Welland Canal. Eventually the Welland Canal was preferred, and it is understood that the Georgian Bay scheme is now dormant although it still has vigorous supporters and may be revived at any time.

W. S. RICHMOND.

SECTION B.

DIVERSIONS FOR SANITARY PURPOSES.

1. CHICAGO SANITARY CANAL.

In the following description and discussion of the sanitary features of the Chicago Sanitary and Ship Canal, and allied projects of the Sanitary District of Chicago, it is not intended to repeat anything already set down in Section A of this report, where the navigation features of both the Chicago Sanitary Canal and the Illinois and Michigan Canal are treated, but only to elaborate sufficiently to make clear the sanitary features. Attention is invited to the maps given on plates 4 and 5 and to photographs Nos. 11 to 16.

Geography of district.—The city of Chicago is situated in what geologists call the "Chicago Plain." This is a crescent-shaped strip of low land lying along the southwest shore of Lake Michigan, bounded by the lake and by a range of low hills called the "Val-paraiso morain." The plain begins at Winnetka on the north and extends along the south shore beyond Gary. Its width varies from 2 to 15 miles.

Three rivers—the Des Plaines, the Chicago, and the Calumet—drain the Chicago Plain. The Des Plaines River rises in the State of Wisconsin and runs nearly due south, parallel with the lake shore, and generally not more than 8 or 10 miles from it, until it reaches a point about 13 miles in a southwest direction from the mouth of the Chicago River. Here is a slight depression a mile or more in width extending across from the Des Plaines to the South Branch of Chicago River through which a part of the waters of the Des Plaines, in time of flood, formerly were discharged into Lake Michigan.

There is little doubt that through this depression there was once an outlet from the Lakes to the Mississippi, which was closed by the recession of the waters of the lake. Even now the surface of Lake Michigan is only 8 or 9 feet below this summit. The Des Plaines River, from the depression described, changes its course and runs in a nearly southwest direction until it joins the Kankakee, forming the Illinois River. Except in floods, the Des Plaines is very shallow, often being reduced in dry seasons to a mere brook, discharging less than 17 cubic feet per second. The valley, however, averages a mile wide and is terminated on both sides by well-marked terraces which become higher and higher as they approach the Illi-

nois. There is much evidence that the water, when this was the great outlet of the lakes, extended from bluff to bluff. The total length of the Des Plaines is about 105 miles.

The Chicago River, flowing at right angles to the lake shore, is only about 1 mile in length. It is formed by the junction of the North and South Branches. The North Branch rises in Lake County and has a length of about 27 miles, roughly parallel to the lake shore and distant from it about 1 to 7 miles. The South Branch has a length of about 4 miles from its forks to the junction with the North Branch. The West Fork originally flowed from Mud Lake near the present Kedzie Avenue bridge and extended east to the forks, a distance of about $2\frac{1}{2}$ miles. The South Fork is about $1\frac{1}{2}$ miles long. Its east arm and west arm each had an original length of a little over 1 mile.

The depression lying between the Des Plaines River and the West Fork of the Chicago River was formerly occupied by a swampy pond or chain of ponds. The early French traders called this "Le Petit Lac," while the English name was "Portage Lake." Later the name "Mud Lake" was commonly used. The lake was about 5 miles long and from one-fourth of a mile to 1 mile in width. It extended from Kedzie Avenue nearly to the Des Plaines River. In very dry summers it was reduced to a mere mud hole. Under more favorable conditions the water was several feet deep and discharged into either the Chicago or Des Plaines Rivers. An early trade route between Canada and the Mississippi Valley ran here and under favorable conditions boats of several tons burthen could be floated through. At other times a portage of from 1 to 4 miles was required. During floods of the Des Plaines a large amount of water was discharged through Mud Lake and the Chicago River into Lake Michigan.

In 1868 the "Ogden Ditch" was excavated through Mud Lake, and six years later the "Ogden Dam" at the southwest end of the ditch was built to keep out the Des Plaines floods. As a result of this construction and of the general settlement and drainage of the surrounding country, Mud Lake gradually disappeared. All that is now visible on its former site is the Ogden Ditch and the upper reaches of the West Fork of Chicago River above Kedzie Avenue.

The Calumet River rises in Laporte County, Ind., and flows in a westerly direction, nearly parallel to the shore of Lake Michigan, a distance of about 45 miles to a suburb known as Blue Island. Here it turns abruptly and takes an easterly direction parallel to its previous course but 2 or 3 miles farther north. It finally reaches its natural outlet to the lake after doubling on itself nearly 22 miles. To distinguish its two parallel portions the southern has been named the "Little Calumet" and the northern the "Grand Calumet."

The natural outlet mentioned above is about $3\frac{1}{2}$ miles east of Gary. It has been practically closed by aquatic growth and drifting sand, and the river now discharges into Lake Michigan through an artificial channel passing between Calumet Lake and Wolf Lake and forming the harbor of South Chicago. It connects with the Calumet near Hegewisch. This channel is said to have been opened by the Indians and traders about 1811. It has subsequently been enlarged by various navigation interests. Since 1870 it has been improved by the Government and now affords an excellent harbor with piers and breakwater affording shelter for the largest lake vessels.

From the extreme westerly point of the Little Calumet River, south of Blue Island, another depression leads west to the Des Plaines River. This is called "The Sag" and is very similar to the one described above between the Chicago and Des Plaines. The Sag is about 15 miles long and rather less than a mile wide. Like the northern depression, it once served as a southerly outlet for the waters of the lake.

Exploration and settlement.—In the late summer of 1673 the exploring expedition of Louis Joliet and Pere Marquette passed through the Chicago portage on their return from their first voyage to the Mississippi. This is the first known appearance of white men at Chicago and the first use by white men of the Chicago-Des Plaines portage. The further use of the portage is recounted by La Salle, Tonty, Joutel, and other explorers during the next dozen years. In 1697 Tonty and La Forest had a warehouse and trading post at "Chicagou" and this is the earliest recorded settlement there. A Jesuit, Father Dablon, made an official report in 1673 on the new discoveries around the western lakes and the Mississippi Valley. In this he proposed the excavation of a ship canal connecting Lake Michigan and the Des Plaines River. This seems to have been the first mention of an idea which has been much in men's minds ever since and resulted, after the lapse of two and a quarter centuries, in the construction of the Chicago Drainage Canal.

During the eighteenth century the Chicago route was much used by traders and travelers. At times white men lived at the lake end, and a fort built there by the French was garrisoned for awhile, but no permanent settlement seems to have resulted. In 1795 Gen. Anthony Wayne made a treaty with the Indians whereby they ceded to the United States, among other lands, "one piece of land 6 miles square at the mouth of the Chicago River, emptying into the southwest end of Lake Michigan, where a fort formerly stood." This treaty also assured the United States the free use of the Chicago-Des Plaines portage. In 1803 Fort Dearborn was built and garrisoned. There was then but one house outside of the fort. In 1812 there were five houses, but at the outbreak of the war with England the fort was abandoned and nearly all of the garrison and settlers were massacred by the Indians. The fort was rebuilt in 1816 and a new treaty signed by which the Indians gave up a strip of land 10 miles wide on each side of the Chicago River, the portage, and the Des Plaines River.

The "town of Chicago" was platted by the Commissioners of the Illinois and Michigan Canal in 1830. It contained about a dozen houses and less than 100 inhabitants. Its growth was slow until the close of the Black Hawk War in 1833. The first census, taken in 1837, showed a population of more than 4,000. Since then the growth has been rapid and continuous, with an average yearly increment of over 8 per cent. In 1918 the population of the city of Chicago was estimated at 2,575,000.

Early sanitary conditions.—The early settlers drew their water supply from shallow wells or from the lake shore. In the thirties water carts did a big business. These were filled at the shore and peddled water from house to house. In 1836 the Chicago Hydraulic Co. was incorporated for the purpose of furnishing a public water

supply. Its water works system went into operation in 1842. The intake was about 500 feet off shore and water was pumped by steam power and distributed through wooden pipes to the South Side and part of the West Side of the city. The North Side was still supplied from wells and carts. The pumping station was at the corner of Lake Street and Michigan Avenue and the intake was close to the mouth of the Chicago River. The river served as a sewer for a large part of the city and was rapidly becoming very foul. By 1850 the water supplied by the hydraulic company was intolerably bad and the supply was quite inadequate, being only sufficient for about one-fifth of the city. An epidemic of cholera occurred in this year.

In 1851 the city obtained the incorporation of the City Hydraulic Co. It bought the rights and franchise of the older company and commenced pumping in 1854. The intake was a basin on the lake shore protected by a breakwater. It was situated at the foot of Chicago Avenue, about 3,000 feet north of the river. For several years the operation of the new works was uniform and satisfactory. Then, as the population of the city and the pollution of the lake shore and river increased, the quality of the water supply again became very bad.

Since 1860 the history of the Chicago water supply shows a steady and continuous growth combined with ever-renewed efforts to get a purer supply by extending the intake farther into the lake to escape the increasing pollution of the shore waters. In 1864 the first tunnel was built. This was 5 feet in diameter and 2 miles long, and had at its outer end an intake crib reaching above the lake surface. The building of new tunnels and intakes has continued at intervals ever since until now there are no less than seven intake cribs. The newest and largest is nearly 4 miles from shore. These great works have cost the city many millions of dollars.

In its youngest days the city was quite without drains or sewers. As the population increased, drainage and sewage was allowed to run in the gutters of the streets. In 1849 the city commenced a comprehensive system of planked streets. Some of these were cut down to a very low grade, in order that the street might drain the abutting property. A few small wooden sewers were built, chiefly on Clark, La Salle, and Wells Streets. They drained into the river and extended no farther south than Randolph Street. By this time the population had reached 30,000 and conditions were very bad. The following extract from a local newspaper in the summer of 1850 gives a picture of the situation:

The wonder is not that we have had cholera in our midst for two seasons in succession, and that the common diseases of the country are fatally prevalent during the summer months, but that a worse plague does not take up permanent residence with us. Many of the populous localities are noisome quagmires, the gutters running with filth at which the very swine turn up their noses in supreme disgust. Even some portions of the planked streets, say, for instance, Lake between Clark and La Salle, are scarcely in better sanitary condition than those which are not planked. The gutters at the crossings are clogged up, leaving standing pools of indescribable liquid, there to salute the noses of passers-by. There being no chance to drain them properly, the water accumulates under the planking, into which flows all manner of filth, and during the hot weather of the last few weeks the whole reeking mass of abominations has steamed up through every opening, and the miasma thus elaborated has been wafted into the neighboring shops and dwellings to poison their inmates.

In the next few years much was done toward draining the swamps that surrounded the city and some 40 or 50 square miles were reclaimed, but provision for city sewage removal made little progress. In 1854 there were only $4\frac{1}{2}$ miles of sewers within the city. In 1855 a board of sewer commissioners for the city was incorporated, which prepared a plan for a comprehensive system of sewers to cover the principal portions of the city. The Chicago River, with its North and South branches, naturally divide the city into three drainage districts. The new sewers of the west and north districts were to drain into the river, while those of the south district drained about half into the river and half directly into the lake. Work was at once commenced on this system. From this time on the growth of the sewerage system has paralleled the growth of the city.

The natural flow of the Chicago River, except at flood times, is very small. As the city grew the distilling and slaughtering industries became very important and discharged vast quantities of waste into the river, which already received the drainage of a rapidly growing city. By 1845 the stream had become terribly offensive. The east and west arms of the South Branch became mere stagnant, scum-covered cesspools or septic tanks which received the blood and refuse from the great packing plants. The other parts of the river were nearly as bad. Unsightly, filthy scum floated on the surface, foul odors from the surface drifted across the city, and deep beds of sludge were deposited on the bottom, to the obstruction of navigation. Summer thunderstorms or sudden lowerings of the lake occasionally set up a current in the river and sent some of its contaminated waters into the lake. The spring freshets of the Chicago and Des Plaines flushed out the whole accumulation of poisonous sludge and scum, and only too often drifted them toward and about the waterworks intakes.

As a natural result of these conditions, the general health of the community was very poor and the death rate from all diseases was high. All intestinal and water-borne diseases were widespread and typhoid fever was endemic. Several severe epidemics of water-borne diseases occurred, notably those of Asiatic cholera in 1834 and 1849 and of typhoid in 1892.

Early sanitary improvements.—The opening of the Illinois and Michigan Canal in 1848 was the first occurrence that tended to improve the bad condition of the Chicago River. This canal had a summit level about 8 feet above the lake which received part of its supply by pumpage from the river. The pumps were located at Bridgeport, at the head of the canal, near what is now Ashland Avenue. While this pumping had been intended only to supply water for the navigation of the canal, it was soon found that it was causing sufficient current in the South Branch to perceptibly cleanse its waters. This led to an arrangement with the canal commissioners in 1865 by which the latter agreed to pump water from the river at certain times for the relief of the city from the serious annoyances of a badly contaminated river. The pumping was chiefly done in the summer and early fall when the river conditions were at their worst. The usual rate was 200 cubic feet per second or a little less.

In 1871 the summit level of the canal was lowered so as to draw its supply directly from the river. It was hoped that this would

result in the establishment of a permanent flow of lake water through the South Branch sufficient to keep it in good condition. These hopes were not realized. The volume discharged down the canal was less than had been expected, while under certain conditions of wind, rainfall, and lake level the flow toward the lake was reestablished. In 1879 there was a lakeward current for 30 days and no perceptible current either way for 10 days. The mean flow was less than 300 cubic feet per second. As the population of the city was now about half a million and the greater part of the sewage went down the canal, its pollution was very great. The dilution obtained probably did not exceed 1 cubic foot per second for each thousand inhabitants. The canal carried a disgusting filthiness and an overwhelming odor throughout its whole length.

In 1881 the protest of the people of Joliet and other parts of the Des Plaines and Illinois Valleys had become so loud that the State passed a resolution requiring Chicago to provide a flow of 1,000 cubic feet per second or abandon the use of the canal for sewage dilution. In compliance with these resolutions the city built a new pumping station of the required capacity at Bridgeport, together with a lock to prevent back flow from the canal into the river. Pumping commenced in 1883. For a few years this afforded sufficient dilution in the canal and there were no more complaints from the valley. Unfortunately when the pumping plant was installed Lake Michigan stood at a very high stage and the pumps were given only sufficient capacity to provide the legal 1,000 cubic feet per second under these conditions. In 1886 the lake level began to fall, and continued to do so until in 1891 it was about 2 feet lower than when the pumps were installed. Their capacity thereby being reduced to a little more than 600 cubic feet per second. As the growth of the city had continued at its usual rate, the nuisance along the canal became at times as bad as ever.

For many years the North Branch of the Chicago River occasioned no serious trouble. It did not receive a great deal of domestic sewage, and most of the slaughterhouses were on the other branch. By 1870 the northward growth of the city and the discharge of the refuse from several large distilleries into the North Branch had produced a serious nuisance there. To abate this the Fullerton Avenue conduit was constructed and put in operation in 1880. This was a 12-foot circular, brick-lined tunnel, about 12,000 feet long, extending from an intake in the lake to the river, along the line of Fullerton Avenue. The pumping station was at the river end of the conduit. The capacity of the pumps was about 400 cubic feet per second. The usual pumpage was something more than half as much. For some years this was enough to keep the North Branch in reasonably good condition.

Development of the drainage-canal plan.—Throughout the nineteenth century the phenomenal and sustained growth of Chicago continually frustrated all attempted solutions of its sanitary problems. On several occasions plans were adopted which were expected to cure certain evils, and before a decade had elapsed after their completion the growth of the city had made conditions as bad as ever.

Much was done by the Citizens' Association of Chicago between the years 1880 and 1889 in creating and fostering a public sentiment which demanded better drainage and water supply for the city. Several expert examinations were made by the association, and its reports were given to the people through the daily papers and printed pamphlets. These investigations and the resulting discussions led to a more exact and complete investigation by the drainage commission under the authority of the city. In 1880 the association referred the question of main drainage to a committee, with a request that they recommend some system for the disposal of the sewage which would be adequate for the present and future needs of the city. In its final report the committee recommended a canal from the South Branch of the Chicago River to the Des Plaines River at Joliet. A drainage district was to be formed including South Chicago, Lake, Cicero, and the towns of the North Shore. The total cost of the project was estimated at \$12,000,000. The importance of this report is found in the fact that it suggested the idea which developed into the law of 1889 creating the Sanitary District of Chicago and providing for the drainage canal.

Prompted by the recommendations of the Chicago Citizens' Association and the urgent appeals of the press, the city council passed a resolution in January, 1886, authorizing the creation of a drainage and water supply commission of three members. Mayor Harrison appointed Rudolph Hering, Benezette Williams, and Samuel G. Artingstall. A preliminary report was made in January, 1887, but the work of the commission was not finished, as the city council was unwilling to provide the necessary funds. The commission recommended a drainage canal system very similar to the one afterward constructed, including the Calumet-Sag branch. The system also included the diversion of the flood waters of the upper Des Plaines and North Branch into the lake by a canal through Bowmanville, some distance north of the city.

In May, 1889, after two and a half years of investigation and debate the State legislature passed the bill creating the Sanitary District of Chicago. The original district was laid out with an area of 185 square miles and included a number of municipalities which were later annexed in large part to the city of Chicago. The project was adopted by popular vote in November, 1889, and trustees were elected the following month. The board organized January 12, 1890. The Supreme Court of Illinois affirmed the validity of the act in June, 1890.

The North Shore was annexed by the act of 1903, thus extending the district to the north line of Cook County. It comprised the townships of Evanston, Niles, and New Trier and parts of three others, an area of 78.6 square miles along the lake shore and in the Chicago River basin, the drainage problems of which are largely identified with those of the original district.

The Calumet region, also annexed by the act of 1903, covered the urban district south of Eighty-seventh Street and west of the Indiana State line. It comprised that part of Chicago south of Eighty-seventh Street, the township of Calumet, and parts of three other townships, an area of 94.5 square miles, wholly in the Calumet Basin, the drainage problems of which are quite independent of

those of the Chicago Basin but are complicated with those of the urban district of the Calumet Basin east of the State line in northern Indiana.

With the annexed territories, the Sanitary District of Chicago covers the entire water front of Cook County, with a shore line of some 33 miles. By subsequent annexation of districts to the west, its total area has been increased to 388.14 square miles. Its estimated population in July, 1918, was 2,764,000, of whom 164,000 live in the Calumet subdivision. The inhabitants of the Calumet drainage basin in the State of Indiana are estimated at about 168,000.

The law of 1889 constituted the sanitary district as a "quasi-municipal corporation" for the purpose of disposing of the drainage and sewage of the communities composing the district. It is empowered to levy taxes within the district and issue bonds on the district's credit. It can develop and sell such new water power as its sanitary operations render available and, in general, do all things necessary for or naturally arising from its main purpose. The law prescribed that any drainage canal constructed must have a flow of at least $3\frac{1}{2}$ cubic feet per second for each thousand persons tributary to it, and must be "kept and maintained of such size and in such condition that the water thereof shall be neither offensive or injurious to the health of any of the people of this State." Where the canal ran through rock it was to have a capacity of at least 10,000 cubic feet per second, and in earth it could be of half this capacity with provision for enlarging to 10,000.

Work was commenced on the excavation of the canal in 1892 and on the collateral improvement of the Chicago River in 1896. A description of the canal and the river improvement will be found in Sections A and C of this report.

An intercepting sewer system covering the lake front from Eighty-seventh Street to the northern city limits was constructed by the city of Chicago. The northern division discharges through a 16-foot conduit between the lake and the North Branch at Lawrence Avenue. This conduit is much larger than would be required for sewage alone, and is used to flush the North Branch by pumping water from the lake. The pumping works are on Lawrence Avenue about three-quarters mile from the lake shore. Pumping began in 1908. In 1917 the mean pumpage from the lake was 169 cubic feet per second. The pumps were not operated to pump water from the lake in February and very little in March, presumably because the spring floods flushed the North Branch sufficiently without artificial aid. The maximum monthly mean pumpage from the lake was 314 cubic feet per second. At times as much as 500 cubic feet per second is pumped from the lake for a few hours. The capacity of the pumping station and conduit is about 873 cubic feet per second, of which 38 is intended for the dry-weather sewage, 250 for the storm-water flow, and the remaining 585 for lake water.

The southern division of the intercepting sewer system discharges through a 20-foot conduit at Thirty-ninth Street. This conduit extends from the lake to the "Stockyard Slip" or east arm of the South Fork. A pumping station on the lake shore at Thirty-ninth Street is intended to pump lake water through this conduit to flush the South Fork. Pumping began in 1907. In 1917 very little pump-

ing of lake water was done; none whatever during nine months. The monthly mean pumpage during each of the other three months was 10, 134, and 27 cubic feet per second, respectively. The capacity of the Thirty-ninth Street conduits and pumps is 2,000 cubic feet per second. Of this 150 is designed to handle the dry-weather flowage, 500 the storm flow, and the remaining 1,350 lake water.

The North Shore Canal extends from the lake shore in the village of Wilmette to the North Branch at Lawrence Avenue, and is intended to provide an outlet for the shore towns and the territory north of the city limits and to furnish additional water for flushing the North Branch. This channel is 26 feet wide on the bottom, 12 feet deep, and about $8\frac{1}{2}$ miles long, and is operated by pumping works at Wilmette. It was opened in 1910. In 1917 the mean pumpage was 548 cubic feet per second, the maximum monthly mean being 770 cubic feet per second. The capacity of the pumps and canal is about 1,000 cubic feet per second.

The part of the Des Plaines River paralleling the drainage canal was straightened and improved, and some levees were built on the east side of the river. A spillway, opened in 1909, leads from the river to the canal at Willow Springs. As a result of these changes the spring freshets of the Des Plaines no longer discharge into Ogden Ditch and the South Branch of the Chicago River.

It is understood that the Fullerton Avenue pumping station, which was formerly used for flushing the North Branch with lake water, is no longer in use.

The yearly mean flow of the drainage canal from its opening to 1917 as reported by the engineers of the Sanitary District is given in Table No. 11.

TABLE No. 11.—Yearly mean diversion through Chicago Sanitary Canal as reported by engineer of the sanitary district in cubic feet per second.

1900.....	2,900	1909.....	2,786
1901.....	4,046	1910.....	3,458
1902.....	4,302	1911.....	6,445
1903.....	4,971	1912.....	6,424
1904.....	4,793	1913.....	7,191
1905.....	4,480	1914.....	7,105
1906.....	4,473	1915.....	6,971
1907.....	5,116	1916.....	7,325
1908.....	4,421	1917.....	7,786

These figures represent the flow at Lockport. They include the natural drainage of the Chicago Basin, the pumpage of the three stations described above, the sewage of the district, and occasional Des Plaines flood water entering by the spillway at Willow Springs. In 1917, when the mean flow was 7,786 cubic feet per second, the maximum flow reported was 17,500 and the minimum 2,150. The maximum daily mean flow in 1917 was 9,891 cubic feet per second and the minimum daily mean 5,184. The maximum monthly mean was 8,907 and the minimum monthly mean 6,916. On a score or more of days between April and November, 1917, the discharge for a time ran very high, the highest peak reported being 17,500 cubic feet per second on September 23. The explanation for these high discharge values, as given by the chief engineer, is that repair work on the walls of the canal necessitated drawing down the canal level on

these days, and this could be accomplished only by opening the controlling works so as to create a very large flow, especially as Lake Michigan stood 1 to 2 feet above datum.

All the values of discharge given in the preceding paragraph are either taken direct or derived from figures submitted by the chief engineer of the Sanitary District. It is believed that they are too small by 5 to 12 per cent. The monthly averages of reported flow through the main canal have been checked against the flow of the Des Plaines River at Joliet as measured by the United States Geological Survey. The gauging section of the Geological Survey does not include the flow leaving Joliet in the Illinois & Michigan Canal, and it does include the natural flow of the Des Plaines above the mouth of the drainage canal. These quantities have been measured separately by the survey. Adding the former quantity to the flow found at the gauging station and subtracting the latter quantity, there results of volume of flow which must have come down the Main Drainage Canal. For the 34 months, March, 1915, to December, 1917, both inclusive, the drainage canal discharge, as computed from the discharge data of the Geological Survey, averages 12 per cent greater than as reported by the Sanitary District, the excess for the month of maximum difference being 19 per cent and for the minimum 5 per cent. Such measurements by the Geological Survey are usually considered reliable within 2 or 3 per cent, with 5 per cent an outside limit. The values given by the Sanitary District, on the other hand, are obtained by computing the discharge of turbines at the power house and of flow over spillways. In computing turbine discharge the machine efficiency is assumed to be that shown by a new model wheel. Usually turbines deteriorate with age and their efficiencies become less, so that they consume more water in producing a given amount of power. It is thought that proper allowance has not been made for this factor. It is also believed that the flow over the wasteways is somewhat greater than as given by the formula used.

Another reason for believing the Sanitary District figures too small is that they give smaller values for the flow on certain days in December, 1913, than actual measurements by the United States Lake Survey. A perfectly satisfactory comparison of the two sets of values is not possible, because most of the Lake Survey measurements were taken when the storage in the canal was accumulating, so that the flow at Lemont, where the Lake Survey measurements were taken, was larger than at the controlling works, 7 miles below. The Lake Survey measurements average 10 per cent larger than the sanitary district figures. On the day when measurements were made almost continuously for 24 hours they show $4\frac{1}{2}$ per cent larger.

The flow in the lower end of the canal always varies considerably during the day, being generally small during the daytime and large at night. The flow is regulated mostly by the draft of water at the power house, which carries a heavy lighting load at night. The Saturday and Sunday loads do not differ greatly from the loads of other week days.

During the 12 hours or more that the heavy night load is on the storage in the canal is being drawn down while the water surface

profile along the canal gradually approaches its new position of equilibrium. This equilibrium requires much more than 12 hours for establishment, and it therefore happens that the flow into the upper end of the canal has not become as great as the flow out of the lower end at daybreak when the lighting load is thrown off. During the daytime conditions are reversed, and the inflow is greater than the outflow, the storage being built up slowly. Because of this fact the diversion from Lake Michigan is never quite as large as the maximum figures indicate, but the monthly and yearly averages are practically free from this effect. A small portion of the diversion is, of course, diverted from the Chicago River watershed, and so is withheld from Lake Michigan but not diverted therefrom. In times of greatest storms this local yield probably equals or exceeds 10,000 cubic feet per second.

The present system.—By the construction of the elaborate drainage system described above the poor sanitary conditions of a half century ago have largely been remedied. All the important sections of the river receive sufficient lake water to keep up a continuous current through them. Septic action no longer occurs in them and no serious nuisance exists. The city's water supply comes from intakes well out in the lake, and under ordinary conditions its quality is very satisfactory. The improvement in sanitation has been reflected in a decrease in the death rate of the city, particularly, of course, in deaths from water-borne disease. The typhoid rate in 1918 was lower than in any other large city of the United States. Down the Des Plaines and Illinois Rivers for many miles the sewage pollution is very noticeable and often offensive, although no really serious nuisance appears to exist. At Ottawa, for example, the river is dark and discolored in appearance, and a stale, strong odor arises which is very disagreeable to persons along the shores or on the river in boats, and is plainly noticeable to those crossing the highway bridge high above the water. A short distance from the river, however, the nostrils do not detect it. All fishes and aquatic vegetable growths have disappeared down to this point and for some distance below. Conditions are better than they were when, in times of very small summer flow, these streams received the sewage of Joliet, Peoria, and other cities. In the lower Illinois River the carp fisheries are said to have improved since the canal was opened. The water-power industries in the valley have been much benefited. The damage to navigation interests in the Great Lakes system is discussed in Sections G and H of this report.

The law creating the sanitary district provided that where sewage was disposed of by dilution the amount of water supplied should be not less than $3\frac{1}{2}$ cubic feet per second for every 1,000 population served. This rate has not been maintained, the apparent reason therefor being the opposition of the shipping interests and the War Department. In the last few years this rate has been reached, or very nearly reached, throughout the greater part of July, August, and September, but only occasionally during the winter and spring. It is the general opinion of sanitary engineers that this rate of $3\frac{1}{2}$ cubic feet per second per 1,000 population represents the lower limit of permissible dilution and that a greater amount is usually needed to give satisfactory results.

There now remain only two things that threaten the purity of the Chicago water supply. One is the discharge of the Calumet River at South Chicago. This carries the drainage from an area of 827 square miles and the sewage of 378,000 people. Normally the lake current at the point of discharge sets to the southeast and carries the pollution away from the Chicago waterworks intakes, but under certain unusual weather conditions the current is reversed and the water supply to the more southerly intakes may be poisoned. The other thing is the occasional restoration of the old eastward flow in the Chicago River, due to sudden intense storms. When a very violent rainstorm strikes the whole Chicago Basin the total run-off becomes very nearly 10,000 cubic feet per second, and possibly more. If the canal is discharging much less than this amount, it is possible that some flow into the lake may occur before the discharge of the canal can be increased enough to carry away the whole storm run-off. If this occurs some pollution of the water supply may result.

The Calumet-Sag Canal.—When the population of the South Chicago region began to increase rapidly, it became evident that its sewage was a considerable menace to the Chicago water supply. In 1903 this region was annexed to the Sanitary District. Its population was then about 100,000. Mr. Rudolph Hering, a well-known sanitary engineer, made a study of disposing of its sewage. He reported that it was feasible to treat the sewage by sprinkling filters and other apparatus so that there would be practically no danger of injuring the Chicago water. He recommended, however, that disposal by dilution through a canal running from the Little Calumet River to the drainage canal was cheaper and more desirable. The proposed canal was to run from the mouth of Stony Creek, on the little Calumet River, about a mile and a half east of Blue Island, to a point on the canal about 3 miles above Lemont. Its length would be about 16 miles. Its discharge capacity was planned to be 4,000 cubic feet per second. This scheme was adopted by the district, except that the capacity was to be made only 2,000 cubic feet per second at first, and later enlarged progressively to the full 4,000 cubic feet per second capacity. As first constructed, the canal was to be 20 feet deep, 60 feet wide in rock, and 36 feet wide at the bottom in earth, with side slopes of 1 on 2 or flatter. When enlarged to ultimate capacity it was to be 22 feet deep, 90 feet wide in rock cut, and 70 feet wide at the bottom in earth cut, with side slopes of 3 on 5. Construction was commenced October 16, 1907, but was soon stopped because of opposition by the War Department. On March 23, 1908, the United States brought suit to restrain the Sanitary District from going ahead with the construction, but mainly for the purpose of determining in the courts the question of jurisdiction. Little or no progress was made in the construction until the Secretary of War, on June 30, 1910, granted a permit to complete the work provided the quantity of water diverted from Lake Michigan through both the Calumet River and the Chicago River together should not exceed the diversion already authorized by the Secretary of War for the Chicago River, namely, 250,000 cubic feet per minute, which is the equivalent of 4,166 $\frac{2}{3}$ cubic feet per second. Beginning in 1911 the work was prosecuted with considerable vigor until at present it is nearly complete, though not in use.

The operation of this canal will prevent sewage from the Calumet region from entering the lake during the greater part of the year. During the spring freshets and during heavy summer rains, however, its capacity will be much too small and a large flow into the lake must result. The drainage area of these rivers is large and flood flow is much greater than in the Chicago River. It has been estimated that the maximum flood flow of the Calumet River exceeds 15,000 cubic feet per second. The flow exceeds the capacity of the Sag Canal many times each year, and each time this happens there will be discharge of sewage into the lake at South Chicago, unless provision is made to keep all sewage out of the Calumet. The situation could be somewhat relieved by opening the old Grand Calumet outlet east of Gary or by the construction of a new artificial outlet, but this would be but a partial cure, as the floods of the Little Calumet alone far exceed the capacity of the Sag Canal. Any such interference with the Grand Calumet drainage would require the cooperation of the State of Indiana.

The "St. Louis-Chicago lawsuit."—On the very day that the drainage canal was opened the State of Missouri brought suit to prevent its use. This suit was a proceeding in equity instituted by the State of Missouri on January 17, 1900, against the State of Illinois and the Sanitary District of Chicago, praying for an injunction against the defendant from draining into the Mississippi River the sewage and drainage of said sanitary district by way of the Chicago Drainage Canal and the channels of the Des Plaines and Illinois Rivers. Later a supplementary bill was filed alleging that since the original bill of complaint was filed the canal has been opened and that all the evil effects apprehended have been produced by it. The introduction of evidence occupied several years. A very large number of witnesses were examined, including many of the leading physicians, bacteriologists, and sanitary engineers of the United States. The expert opinions of these men were extraordinarily divergent and in many cases absolutely contradictory. Some claimed that the operation of the sanitary canal had made the St. Louis water supply dangerous and unsatisfactory, while others claimed that it had improved the quality and safety of that supply. The case was argued before the Supreme Court of the United States in October, 1905. The court apparently felt that real damage to the St. Louis water supply was not definitely proven, for on February 19, 1906, the case was dismissed without prejudice. If better evidence or proofs were discovered on the Missouri side a similar suit might be brought a second time, but no such action has been taken.

The Federal permits.—Mention has already been made in the description of the Calumet-Sag Canal of certain permits issued by the Secretary of War. The first request for a Federal permit made by the Sanitary District of Chicago was addressed to the Secretary of War under date of June 16, 1896, at which time excavation of the main drainage canal was well under way. This request was to widen and deepen the South Branch of Chicago River at designated points in order that it might have capacity to conduct to the head of the artificial canal a flow of 5,000 cubic feet of water per second at a velocity of $1\frac{1}{2}$ miles per hour. The request was granted by letter of the Secretary of War, dated July 3, 1896, under specified conditions,

among which was the following: "That the authority shall not be interpreted as approval of the plans of the Sanitary District of Chicago to introduce a current into Chicago River. This latter proposition must be hereafter submitted for consideration." Further permits respecting Chicago River improvement were granted November 16, 1897, November 30, 1898, January 13, 1899, March 10, 1899, and May 12, 1899.

On April 22, 1899, the Sanitary District made application to the Secretary of War for permission to open the canal as soon as completed and discharge through it waters of Chicago River and Lake Michigan, reversing the current in Chicago River. This permit was granted May 8, 1899, it being expressly stipulated that the permit was temporary and revocable at will; that it would be changed if found necessary to protect commerce in the river from unreasonable obstruction because of the current, or to protect property from injury; and also, "That it is distinctly understood that it is the intention of the Secretary of War to submit the questions connected with the work of the Sanitary District of Chicago to Congress for consideration and final action, and that this permit shall be subject to such action as may be taken by Congress."

An additional permit with reference to improvement of Chicago River was granted July 11, 1900.

On April 9, 1901, the permit of May 8, 1899, was modified, restricting the flow through Chicago River and its South Branch to a maximum of 200,000 cubic feet per minute, equal to $3,333\frac{1}{3}$ cubic feet per second. The permit recites that "it is alleged by various commercial and navigation interests that the present discharge from the river into the drainage canal sometimes exceeds 300,000 cubic feet per minute, causing a velocity of nearly 3 miles per hour, which greatly endangers navigation in the present condition of the river." Upon application of the sanitary district, another modification was made by the Secretary of War on July 23, 1901, permitting a flow of 300,000 cubic feet per minute between the hours of 4 p. m. and midnight, each day. Another permit, dated December 5, 1901, set the rate of flow at 250,000 cubic feet per minute (4,167 cubic feet per second) throughout the 24 hours of each day. Upon application of the sanitary district, dated December 29, 1902, a permit of the Secretary of War was issued on January 17, 1903, granting permission to divert 350,000 cubic feet per minute during the closed season of navigation and requiring reduction to 250,000 cubic feet per minute after March 31, 1903. This permit is still in force.

Wishing to construct the Calumet-Sag Canal and divert Lake Michigan water through it, thereby reversing the current in the Calumet River, the Sanitary District on November 28, 1906, made application to the Secretary of War. On March 14, 1907, the petition was denied. Another similar application was made June 27, 1910. Thereupon the Secretary of War, on June 30, 1910, granted a permit to complete the canal and appurtenant works, provided "that the amount of water withdrawn from Lake Michigan through the Chicago and Calumet Rivers together shall not exceed the total amount of 250,000 cubic feet per minute (4,167 cubic feet per second) already authorized to be withdrawn through the Chicago River alone."

Meantime, on September 11, 1907, the Secretary of War issued a permit to connect the North Shore Canal with Lake Michigan at

pert witnesses was called on each side. The arguments of counsel on the law and facts were presented in 1915. The decision of the district court has not been rendered.¹

It developed in the testimony that the defendant's witnesses did not deny the lowering of lake and river levels or injury to navigation, but belittled them. The controversy was over the extent of the lowering, held by the defendant to be only about 60 to 80 per cent as great as by the complainant, and the amount of the damage to navigation was held by the defendant to be much less than by the complainant. Admission was made that the diversion had for years greatly exceeded 4,167 cubic feet per second.

It was also admitted that sections 9 and 10 of the river and harbor act of March 3, 1899, were constitutional. Inasmuch as construction of the drainage canal was commenced September 3, 1892, and was nearly complete on March 3, 1899, the defendant argues that this act could not be applied. The complainant points out that sections 9 and 10 were mainly corroborative of section 10 of the river and harbor act of September 19, 1890, which was passed prior to the commencement of construction of the drainage canal and constitutes all needed authority in the case. The Sanitary District points out that it is empowered and required to dispose of the sewage by dilution under the sanitary district act of the State of Illinois, passed May 29, 1889, prior to both river and harbor acts noted above. The Government shows that, although the sanitary district act was passed May 29, 1889, nothing pertaining to the construction of the canal was accomplished until after September 19, 1890.

In the testimony the defendant claims the financial burden caused the district by a strict limitation to a diversion of 4,167 cubic feet per second would be approximately \$250,000,000.

Jurisdiction of Federal Government.—It appears that the jurisdiction of the Federal courts and legislature over the question of diversion of water through the drainage canal arises from three constitutional considerations, namely, that the Federal Government is the only agency that can deal with questions of foreign relations; that the Federal Government has to deal with disputes and damage claims between different States; and that Congress has jurisdiction over the maintenance and improvement of navigable waterways. The diversion of water at Chicago affects the regimen of the Mississippi River and increases flood heights in 7 States, all of which have spent money for flood protection, changing conditions in about 1,000 miles of navigable channel in the Mississippi and its branches, much of which has been improved by the Federal Government. This diversion also has an adverse effect on the depths of the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers, which are all navigable streams improved by Federal aid, on the depths of five great Government ship locks, and on the depths in more than 100 harbors and channels on the Great Lakes which are dredged and maintained by the Federal Government. It has reduced the depths on the sills of the Lockport and Oswego locks of the New York State Barge Canal and has injured local harbor improvements in seven States. Similar damage has been done to a score of the Canadian harbors, to the three great Canadian ship canals, and to the St.

¹ District judge rendered an opinion June 19, 1920, decreeing that the Sanitary District be enjoined from diverting more water than authorized by the War Department.

Lawrence River where it runs through Canadian territory. These many and intricate matters of interstate and international importance can not justly be dealt with by the State of Illinois alone, but are proper subjects to be handled by the National Government.

The future.—The greatest single factor in creating Chicago's sanitary troubles has not been her geographical position, nor the nature of her soil, nor the presence of the packing-house wastes. It is the unprecedentedly great and sustained growth of the city that has repeatedly frustrated all solutions. If this growth continues, the drainage canal will become an inadequate sewer just as the Illinois & Michigan Canal did 40 years ago. By 1950 the sanitary district may be reasonably expected to contain 5,000,000 people, while 6,000,000 or 7,000,000 or even more would not be beyond the bounds of possibility. If this happens, the thickly inhabited urban region will very likely spread to the south and west, and the sanitary district will have to be extended to cover nearly all of Cook County and the eastern third of Du Page County. The ultimate possible population of the territory centering on the Chicago River, whose sewage must be kept out of Lake Michigan, exceeds 15,000,000 in Illinois, with perhaps 10,000,000 more in Indiana.

The legal rate of dilution which the sanitary district is required to maintain is $3\frac{1}{2}$ cubic feet per second for each 1,000 inhabitants. That would require a discharge of 8,670 cubic feet per second to serve the present population if the Calumet-Sag Canal is not in operation, and 9,220 cubic feet per second, including the Calumet district. The total capacity of the canal, at its usually estimated value of 14,000 cubic feet per second, would afford the legal dilution for the sewage of 4,200,000 people. If the district be granted the use of 14,000 cubic feet per second, in 20 or 30 years it must come back and ask for more in order to continue extending the dilution method. To supply the legal dilution for a population of 15,000,000 would require 50,000 cubic feet per second. This is far in excess of the present capacity of the Illinois Valley. It would add to the floods of the Mississippi, and would so lower the Great Lakes and their connecting waters as to require a complete readjustment of the whole Lake system of navigation.

It is evident that dilution by means of the Chicago Drainage Canal can not be considered as a permanent solution of the sanitary problems of the district. On the other hand the great convenience of the present system and the fact that some hundred millions of dollars have already been spent on it are points on the other side that should be taken into account. The fact is that this question is one that can not properly be decided by the uncompromising victory of one or the other of the conflicting interests involved. It should rather be settled by Congress from the point of view of the greatest value to the whole country. The 13 States interested, the Dominion of Canada, the City and Sanitary District of Chicago, the shipping interests of the Great Lakes, the water-power interests, should each be allowed to present their case, and every effort be made to safeguard the interests of each with due regard to the rights and necessities of the others. Without going into details it may be said that the final decision might well contain the following elements: (1) The Sanitary District to be allowed the use of such water as may be found necessary to dispose of by dilution the sewage now entering the

Chicago River, and to prevent any flow from the Chicago River into the lake during storms. (2) Works to be built on the rivers of the Great Lakes system to compensate for the lowering of water levels due to this diversion. These works to be designed and built jointly by the United States and Canada and paid for by the Sanitary District of Chicago. (3) The Sanitary District to be prohibited absolutely from any further diversion, regardless of increase in population, and directed to proceed forthwith to formulate a comprehensive scheme of purification, and to proceed with its installation in order that any effluent discharged into the Des Plaines or Illinois Rivers can be sent down the valley without nuisance or danger even though the dilution obtained is much less than $3\frac{1}{4}$ cubic feet per second per thousand of population. (4) The diversion to be so effected as not to hinder navigation in the Chicago River. (5) The question of the Sag Canal to have special consideration, thought being given to the future needs of Gary, Indiana Harbor, Hammond, and the other towns in Indiana on the Calumet drainage. Diversion through the Calumet-Sag Canal to be allowed only if a comprehensive scheme can be devised which will protect the purity of Lake Michigan in spite of spring floods or summer thunderstorms. (6) The pollution of lake waters by ships to be prevented. (7) A fair license fee per cubic foot of water per second diverted to be paid the Federal Government.

2. BLACK RIVER CANAL.

The Great Lakes drainage system contains no less than 18 streams bearing the name "Black River" or "Black Creek." The Black River considered here rises northwest of Port Sanilac, Mich., about 11 miles west of Lake Huron, flows south, passes through the city of Port Huron, and enters the St. Clair River about $2\frac{1}{4}$ miles below the foot of Lake Huron. Its length is about 65 miles, and it drains about 450 square miles of territory. During the spring freshets the discharge of this river amounts to several thousand cubic feet per second, but during the summer months there is practically no flow.

The sewage from a large part of Port Huron is discharged into this river, including very foul wastes from a sulphite pulp mill. Formerly, during the summer months, the lower part of the river became a stagnant cesspool extending through the heart of the city. The unsightly appearance and extremely offensive odor of the stream constituted an intolerable nuisance.

To remedy these conditions the city constructed a canal from Lake Huron to a point on the river above the city. Through this channel there now flows a constant current of water, preventing stagnation in the lower reach of the river. The canal leaves Lake Huron at a point about $1\frac{3}{4}$ miles above Fort Gratiot Light, and runs directly to the nearest bend of the river, a distance of about 5,800 feet. It hits the river $4\frac{1}{4}$ miles above its mouth. The canal has a bottom width of 25 feet with side slopes of approximately $1\frac{1}{2}$ to 1. The average depth of water is 6 feet. The fall from the head of the canal to the mouth of Black River averages about 1.25 feet, which is approximately one-quarter of the total fall of the St. Clair River. The maximum fall is said to be about $2\frac{1}{4}$ feet. This fall occurs almost entirely in the canal itself.

The mean discharge is reported to be about 400 cubic feet per second, and the maximum about twice as much. Construction of the canal was commenced in 1901 and completed in 1912. The cost was about \$125,000. The upper end of the canal is frequently partly blocked by sand and gravel from Lake Huron and requires considerable dredging to keep it clear. Aside from this difficulty the operation of the canal has been entirely successful and the results desired have been obtained.

The effect of this diversion is treated briefly in Section G of this report. The principle involved is important, but the actual effect is very slight.

Photographs Nos. 50 and 51 show, respectively, the head of the Black River Canal and the mouth of Black River.

3. PROPOSED ERIE AND ONTARIO SANITARY CANAL.

The proposed power, ship, and sanitary canal of the Erie & Ontario Sanitary Canal Co. has been described in section A of this report. It is understood that the sewage of Lackawanna and other southern and eastern suburbs of Buffalo will be discharged directly into this canal. Buffalo Creek is to be reversed, and its flow, together with the 4,000 or 5,000 cubic feet per second admitted to the branch canal at Black Rock, is expected to cause a constant inflow of Lake Erie water into Buffalo Harbor. All the sewage will then go down the canals and none down the river except a very little through the Black Rock ship lock. The sewage of Black Rock, North Buffalo, and Tonawanda will discharge directly into the branch canal. North Tonawanda would probably be connected with the main canal by a trunk sewer or, possibly, would discharge its sewage into the barge canal. Intercepting sewers would be required along the river front of both the Tonawandas to collect sewage now discharged into the river. The estimate submitted by the company provides for rough screening of the sewage before it enters the canal, and in some of the prospectuses an offer is made to give it whatever further treatment it may require to prevent forming dangerous or offensive conditions in Lake Ontario.

The proposed diversion of water is 26,000 cubic feet per second. This is described in the draft of a bill submitted by the company as "the use of 20,000 cubic feet of water per second allowed by the treaty with Great Britain for power, together with 6,000 cubic feet of water per second further allowed by article 5 of said treaty for sanitation and navigation."

The present population of the area to be served by the canal is perhaps 600,000. Allowing for future growth, 6,000 cubic feet per second is about the quantity that would be required to dilute the sewage from this district and carry it away without creating any serious nuisance. Under the proposed scheme, when 20,000 cubic feet per second have been diverted for power development all the sewage of this region could be properly diluted and carried away by the same water. In fact, the dilution would be more than three times as great as is usually considered necessary. To divert 6,000 cubic feet per second additional for "sanitary purposes" is a proposal of doubtful justification. Whether or not it would be possible

without violating the provisions of the treaty is a question of law. It appears contrary to the intent of the treaty.

That the water of the Niagara River is now contaminated and polluted by sewage can not be denied. Without purification it is not fit to drink. The city of Buffalo gets its water supply from an intake which normally receives Lake Erie water with little or no contamination from Buffalo or Lackawanna sewage. Under unusual conditions of winds and currents it may be so contaminated. The cities of Tonawanda, North Tonawanda, Lockport, and Niagara Falls receive a supply that is seriously polluted. The solution of the problem of giving these cities a satisfactory supply can be attempted by two different methods. It may be determined, on the one hand, to bring the whole 207,000 cubic feet per second of the Niagara River water into a pure, safe, potable condition and retain it so. On the other hand some pollution, devoid of gross nuisance, may be permitted, the main effort being directed toward purification of the 300 or 400 cubic feet of water per second which is pumped to supply the cities of the Niagara frontier, including Buffalo.

The very thorough investigations by the International Joint Commission have shown conclusively that the water of Lake Erie does not afford a safe domestic supply. It is contaminated by the waste of the many cities on its shores and of the vast fleet on its waters. The rapidly increasing population of both shores of the river and of Grand Island adds its pollution to the river waters. After the utmost has been done to exclude the sewage of Buffalo and its suburbs from the river, the water will still need treatment before it is fit for use. The solution of the problem by the first method will necessarily be incomplete.

While the first method tries to maintain the waters of an immense river, draining a settled area of 276,000 square miles, in a pure and potable condition, the second method applies intensive methods of purification to the small quantity of water which needs to be pure. Only about one six-hundredths of the flow of the river need be treated. That this may surely and economically be accomplished is abundantly demonstrated by the experience of the city of Niagara Falls.

Niagara Falls was formerly supplied by the Western New York Water Co., with untreated Niagara River water taken from near the American shore. The supply was badly polluted by the sewage of Buffalo, the Tonawandas, La Salle, and Echota. The dangerous nature of the water was notorious, and intelligent people depended largely on wells and bottled spring water for their drinking water. Nevertheless, typhoid fever was endemic to a marked degree. The typhoid death rate varied from 93 to 224 per 100,000 and was one of the highest in the United States. As the city is visited by more than 1,000,000 sightseers every year, it served as a focus of infection for spreading the disease over the entire country. In 1912 the city opened a municipal waterworks with mechanical filters, and soon after the Western New York Water Co. began chlorinating its supply. The typhoid rate fell at once, and since then has been only about one-tenth as great as before. Table No. 12 shows the death rates due to typhoid fever since 1903, expressed as deaths per 100,000 of population:

TABLE No. 12.—*Typhoid fever death rate per 100,000 in Niagara Falls, N. Y., 1903 to 1917.*

1903.....	212	1912 ¹	28
1904.....	153	1913.....	25
1905.....	224	1914.....	10
1906.....		1915.....	
1907.....	148	1916.....	11
1908.....	96	1917.....	10
1909.....	93		
1910.....	102	Mean of 6 years.....	14
1911.....	167		
Mean of 8 years.....	149		

The International Joint Commission has made a very extended and thorough study of the pollution of boundary waters, including Niagara River. The commission recommends sewage treatment by Buffalo and other cities along the river to an extent which will abate present nuisances and greatly lessen the dangers from pollution, holding that purification of water supplies will still be required, the sewage-purification processes providing a "margin of safety" for the water-supply purification works. The report of the commission was, in part, as follows:

The reference specifically calls for consideration by the commission, of drainage canals as a possible way or means of remedying or preventing the trans-boundary effect of pollution. The only suggestion that has been made before the commission of a drainage canal project is that promoted by the Erie & Ontario Sanitary Canal Co. This company was organized primarily for power purposes, but among the objects in its application for incorporation is remedying the pollution of the Niagara River by the construction of a canal starting at or near the mouth of Smokes Creek in the city of Lackawanna and thence running through a well-settled country to Lake Ontario. It is proposed that the canal should be used free of charge by the cities of Lackawanna, Buffalo, Tonawanda, North Tonawanda, Niagara Falls (United States), and Lockport, and by other municipalities and communities on the United States side of the Niagara River to carry off their sewage and storm flows, which are now discharged into Lake Erie and the Niagara River, provided each city or town make its own connection with the canal without expense to the company. The company applied to the Secretary of War for the United States by application dated April 23, 1912, for permission to divert for its purposes 6,000 second-foot of water from Lake Erie and the Niagara River. The necessary authority for the diversion of this water was denied by the Government of the United States, but the company desired to secure from the commission an approval of the canal as a feasible solution of the pollution problem in the Niagara River. Opportunities were afforded the company to appear before the commission on several occasions. The company's president, Mr. Millard F. Bowen; its counsel, Mr. George Clinton, and others on its behalf made at the different sittings able and lengthy arguments, and briefs were submitted to the commission containing statements of fact and arguments from Messrs. Randolph, Clinton, Bowen, and Shiras in support of the scheme. Quite a large amount of evidence was taken, as will appear on reference to the records of the commission. The financial and sanitary features of the project did not, however, appear to have been sufficiently investigated. The plans and data submitted were consequently referred to the consulting engineer for further investigation and report. His report was decidedly adverse to the undertaking for two principal reasons: (1) It proposed to receive sewage in its raw condition into the canal, thus creating a large open sewer. A condition of serious menace would therefore obtain throughout its length, and if the sewage were allowed to pass into Lake Ontario conditions there would be at least no less objectionable than they are at present. (2) The treatment required to prevent nuisance in such a canal would necessarily be more complete and correspondingly expensive than treatment required for the protection of the Niagara River, a result due to the com-

¹ Filter installed.

paratively small volume of diluting water available in the canal and the consequent necessity for thorough treatment of the sewage by expensive oxidizing methods. These reasons would apply with much greater force in the future. Buffalo and the towns below are rapidly growing. Should their combined population reach a total of 1,000,000, the diluting power of the diverted water would be so inadequate that during the summer months the waters of the canal would be devoid of oxygen, dark in color, and foul smelling. One nuisance would be abated by the creation of a much greater nuisance, which could only be corrected by the most intense sewage purification. The commission, after full consideration of all the features of the project, is of the opinion that besides being objectionable on other grounds it is inadvisable as a sanitary measure.

On the general question of drainage canals as a method of sewage disposal the commission is unable to express any opinion, as each case must be decided upon its merits. Consideration of any scheme involves a study of the amount of water available for diversion, the water-carrying capacity of the canal, the amount of raw sewage to be discharged into it, the character and cost of treatment of the sewage to be carried, and the consequent interference with the many other interests which may be affected, all of which elements vary according to local circumstances and conditions.

It thus appears that the proposed sanitary canal will not make the Niagara River a safe and satisfactory water supply for the frontier cities without further treatment by individual communities. The studies and estimates in Section F of this report show that a combined power and ship canal on the La Salle-Lewiston route would develop as much power as the proposed sanitary canal, would be a much better ship canal, and would be much cheaper. The difference in cost of the two canals would be far more than enough to provide water purification plants for all the frontier cities. Moreover, if these cities build such plants, the cost will be borne by the people benefited, while under the plan of the Erie & Ontario Sanitary Canal Co. the cost of providing better water for these cities is to be added to the price of power and borne by the customers of the company. Surely this is an inequitable arrangement.

The conclusion must be that, considered as a sanitary project, this scheme has little to recommend it. Its navigational and power aspects are treated in Sections A and F, respectively, of this report.

4. DIVERSIONS OF CITIES.

The only remaining diversions of water from the Great Lakes system for sanitary purposes are the diversions of cities bordering the Great Lakes and outflow rivers for water supply and sewer flushing. The most notable example of flushing is that at Milwaukee, where nearly 1,000 cubic feet of water per second is pumped at three pumping stations to flush the Milwaukee, Menomonee, and Kinnickinnic Rivers. In this instance the lake water used in flushing these rivers and a few trunk sewers is soon returned to the lake within a few miles of the points of diversion. At Chicago the pumpage for water supply is about 1,050 cubic feet per second. The experience of sanitary engineers is that practically the full amount of the water supply eventually finds its way into the sewers. In the case of Chicago the sewage passes down the drainage canal, hence the water supply forms a part of the diversion measured at Lockport, and previously discussed in this section. The other cities all return their supplies to the lakes and connecting waters within a few miles of the point of diversion. The quantities are small. At Buffalo the diversion is

approximately 220 cubic feet per second. At Detroit, the largest lake city after Chicago, it amounts on the average to 225 cubic feet per second. The effects of all these diversions, except that at Chicago, upon lake levels or navigation are absolutely trivial.

W. S. RICHMOND.

SECTION C.

DIVERSIONS FOR POWER PURPOSES.

1. ST. MARYS FALLS CANALS.

The total diversion of water at Sault Ste. Marie for power development is approximately 43,000 cubic feet per second. At the rapids of the St. Marys River at Sault Ste. Marie there is a head of from 17 to 21 feet which is available for power development. The mean flow of the river, including the ship canals and power canals, is about 75,000 cubic feet per second. It thus appears that a little more than half of the river flow is used to develop power. The total power production averages about 54,750 horsepower. The compensating works which prevent this use of water from lowering Lake Superior unduly are described in Section G of this report, which deals with lake levels.

There are three power plants at Sault Ste. Marie, one on the Canadian side and two on the American. The location of each is shown on the map on plate No. 3.

Government plants.—The United States Government power plant is located in the rapids on the American side abreast of the west end of the fourth lock. A small plant was first constructed by the Edison Sault Light & Power Co. in 1887, and was extended from time to time. It was located a little south of the present site. In 1906 the present plant was built, extending farther into the rapids than the earlier one, and estimated to divert about 1,400 cubic feet per second.

The plant was acquired by the United States in 1912 and leased to the Edison Sault Electric Co. by the Secretary of War under date of June 25, 1912. Under the terms of this lease the plant was enlarged in 1915-16 and another unit added, making a total installation of about 2,575 horsepower. The lease contemplates a final development of 5,335 horsepower over and above the power required by the United States for lighting and operating locks and other purposes.

The headrace of this plant is formed by a dike about 2,700 feet long extending downstream from one of the piers of the International Bridge at the head of the rapids, and is closed at its lower end by a pier, sluice gates, and the power house. The total length of this headrace is about 2,100 feet, its width is about 700 feet, and its depth varies from 2 to 10 feet. The gross head varies from 17 to 21 feet, the head at the power house ranging from 17 to 19½ feet. A tailrace approximately 100 feet wide leads downstream from the power house about 1,700 feet to a point near the foot of the rapids.

The power house contains five units. Four of these are 71-inch Sampson turbines, each with vertical shaft direct connected to a 450-kilowatt generator delivering three-phase alternating current. The fifth unit is a 60-inch Allis-Chalmers vertical-shaft turbine direct connected to an alternator. There are also two small turbines, rated at 110 horsepower each, which drive the exciters. The average power

developed is 750 horsepower. The water consumed is 1,030 cubic feet per second, of which 500 cubic feet per second is estimated to be wasted through the sluices or lost by leakage through the dike.

Part of the power is used by the United States for lighting and operating locks and the remainder carries a miscellaneous light and power load in the city of Sault Ste. Marie, Mich. The contemplated ultimate development of 5,335 horsepower over and above the power required by the United States will probably require a diversion of somewhat more than 4,000 cubic feet per second.

Michigan Northern Power Co.—The plant of the Michigan Northern Power Co. is on the American shore about a mile below the locks and is supplied with water by a canal running from near the western entrance of the ship canal. This canal or headrace is about 12,000 feet long. The downstream portion has a trapezoidal cross section 162 feet wide on the bottom, 200 feet wide at the water surface, and about 24 feet deep, lined with timber. The upper part is a rock cut of equivalent size. The gross head varies from 17 to 21 feet. The net head at the power house at present is about 16 feet.

The power house contains 79 pairs of turbines, 15 pairs of 34½-inch and 64 pairs of 33-inch, direct connected by horizontal shafts to small electric generators. The average amount of water used is 30,000 cubic feet per second and the average power output is 35,000 horsepower. Part of this power is used for street railway operation, but the bulk of it is used in the manufacture of calcium carbide in the nearby plant of the Union Carbide Co.

This plant was built by the Michigan Lake Superior Power Co. in 1898–1902. About 8,500 cubic feet per second were used in 1906. In 1909, 35 out of the 42 units installed were generally in use. About 12,000 cubic feet of water per second was being consumed, and the average output was about 11,000 horsepower. In 1913 the name was changed to Michigan Northern Power Co., and under terms of a lease executed by the Secretary of War May 28, 1914, the company completed its plant by the addition of 37 new units. No further extension of the plant is contemplated, but the amount of water used may be increased by perhaps 10 per cent.

Great Lakes Power Co.—The plant of the Great Lakes Power Co. is in Sault Ste. Marie, Ontario, about 500 feet north of the eastern gates of the Canadian lock. The headrace leads from the bay north of the upper entrance to the Canadian ship canal. It is a little more than 2,000 feet long, 4,500 including channel through the bay, and is now being enlarged to a width of 400 feet and depth of 12 feet. The gross head varies from 17 to 21 feet, the head at the power house averaging about 18 feet.

The old power house contains three old 51-inch 350-horsepower McCormick turbines which are connected to dynamos by gears. The new power house contains 24 modern vertical-shaft hydroelectric units. These are Allis-Chalmers turbines rated at 825 horsepower each. The pulp mill contains 12 units, each consisting of five 31-inch American runners mounted on a horizontal shaft and rated at 1200 horsepower. These drive the pulp grinders. The total rated power of the installation is approximately 35,000 horsepower at a head of 18 to 18.5 feet. The average power developed is 19,000 horsepower and the average water used is 12,000 cubic feet per second. This



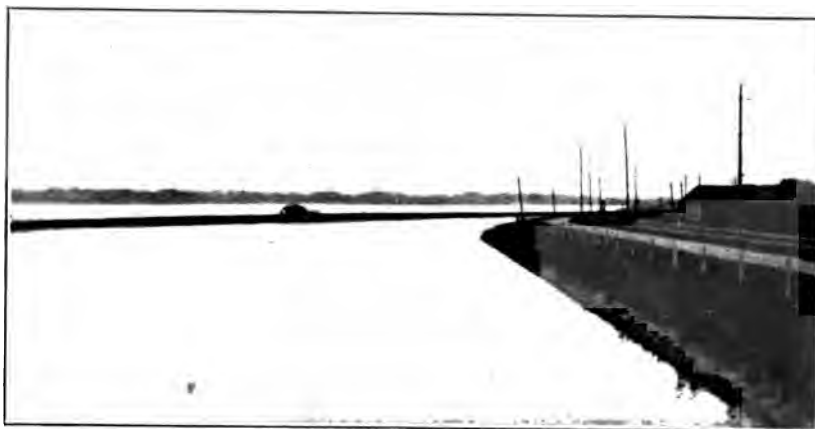
Photograph No. 45.—NEW YORK STATE BARGE CANAL.
By-Pass at Lockport, N. Y



Photograph No. 46.—NEW YORK STATE BARGE CANAL.
Guard Lock No. 72, Old Erie Canal, Hamilton Street, Buffalo, N. Y.



Photograph No. 47.—ST. LAWRENCE CANALS.
Waste Weir and Gates at Lock No. 27.



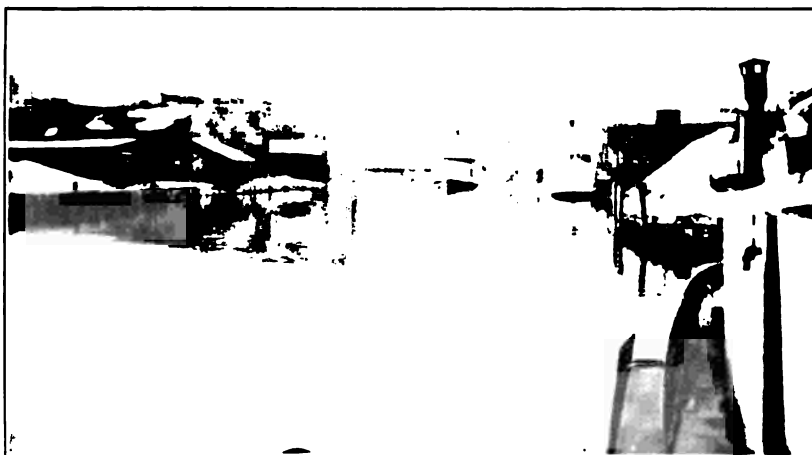
Photograph No. 48.—ST. LAWRENCE CANALS.
Galop Canal above Iroquois, Ontario.



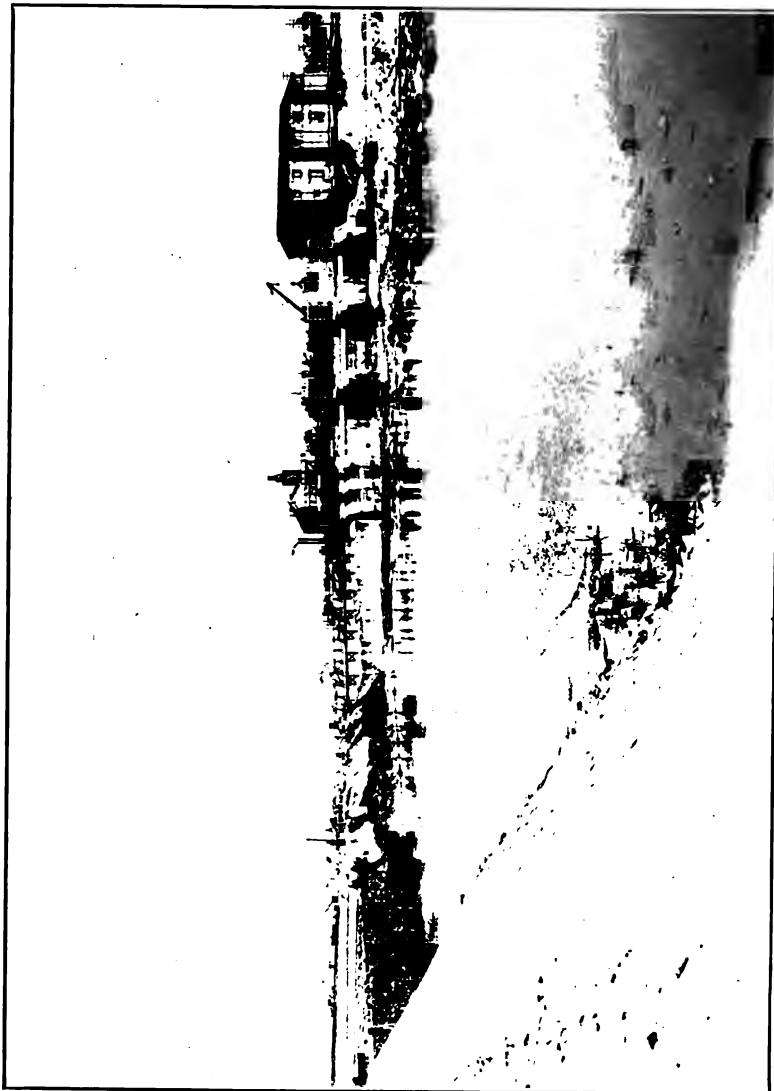
Photograph No. 49.—ST. LAWRENCE CANALS.
Lock No. 24.



Photograph No. 50.—HEAD OF BLACK RIVER CANAL, LAKE HURON.



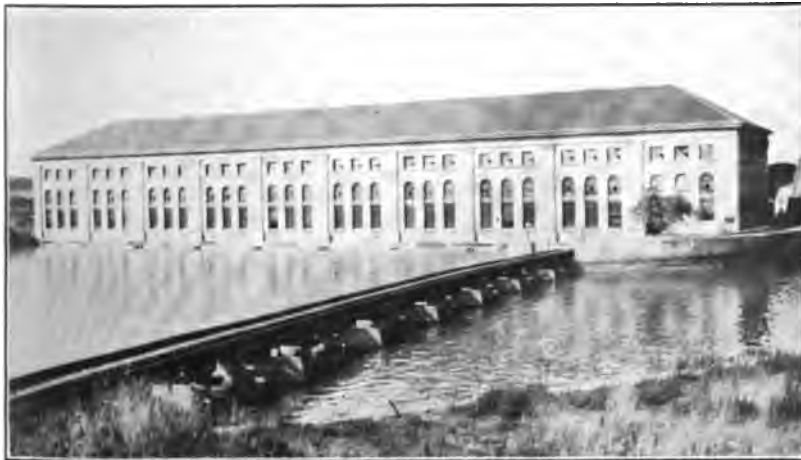
Photograph No. 51.—MOUTH OF BLACK RIVER, PORT HURON, MICH.



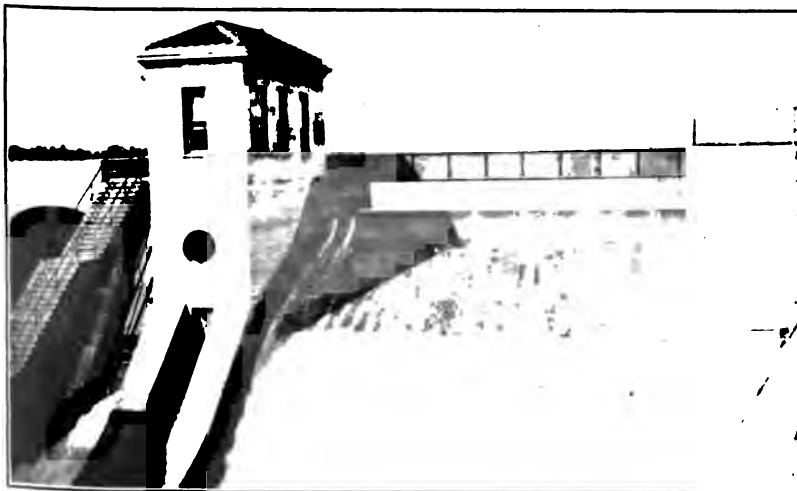
Photograph No. 52. CONTROLLING WORKS AND GOVERNMENT POWER HOUSE, SAULT STE. MARIE, MICH.



Photograph No. 53.—CANAL OF MICHIGAN NORTHERN POWER CO., SAULT STE. MARIE, MICH.



Photograph No. 54.—POWER HOUSE OF SANITARY DISTRICT OF CHICAGO, ILL.



Photograph No. 55.—SECTOR DAM AT POWER HOUSE OF SANITARY DISTRICT OF CHICAGO, ILL.



Photograph No. 56.—POWER HOUSE AT JOLIET, ILL.



Photograph No. 57.—DAM ON ILLINOIS RIVER AT MARSEILLES, ILL.



Photograph No. 58.—MAIN POWER CANAL AT MARSEILLES, ILL.



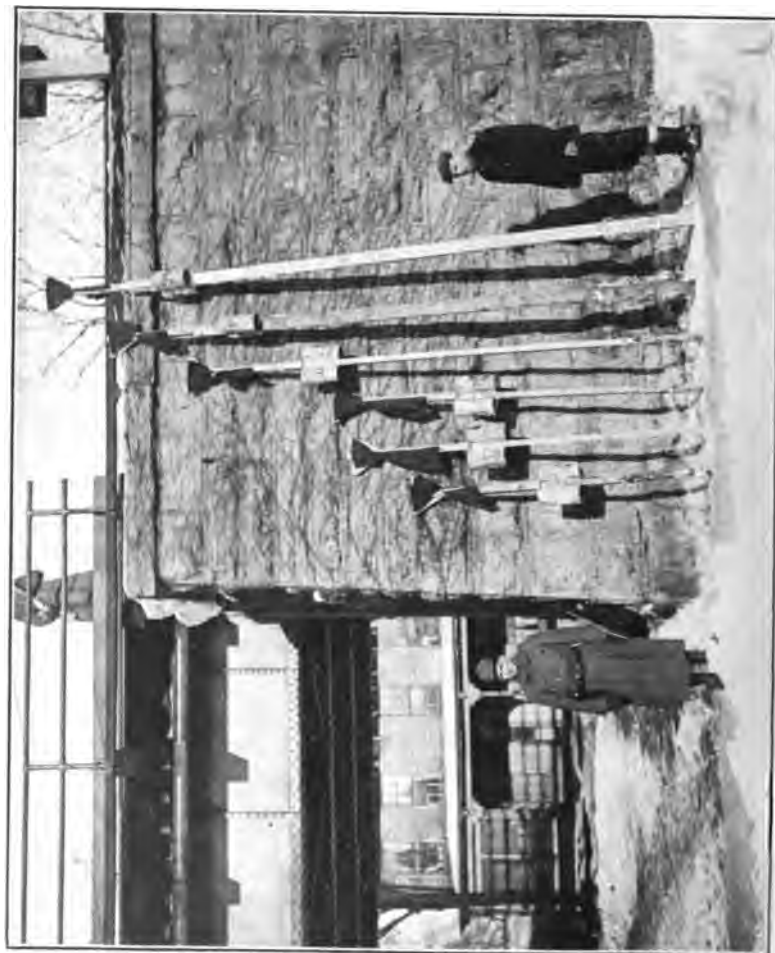
Photograph No. 59.—MILLS AND POWER HOUSES BELOW MARSEILLES DAM.



Photograph No. 60. —MILLS NEAR LOCK NO. 3, OLD WELLAND CANAL.



Photograph No. 61. —MILLS NEAR LOCK NO. 2, OLD WELLAND CANAL.



Photograph No. 62.--ROD FLOATS USED IN SURVEY OF NIAGARA RAPIDS.



Photograph No. 63.—SURVEY OF HORSESHOE RAPIDS.
Field Parties observing Floats from ☉ J.



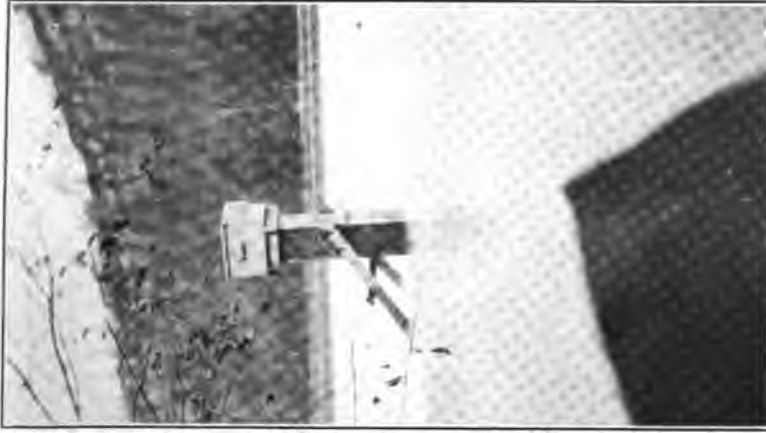
Photograph No. 64. SURVEY OF HORSESHOE RAPIDS.
Field Parties observing Floats from © D.



Photograph No. 65. CHIPPAWA GAUGE.



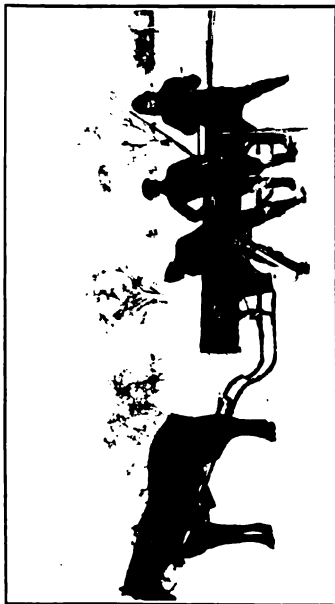
Photograph No. 66.—INTERNATIONAL RAIL-
WAY INTAKE GAUGE.



Photograph No. 67.—SUSPENSION BRIDGE
GAUGE.



Photograph No. 68.—PROSPECT POINT GAUGE.



Photograph No. 69.—ROCK SOUNDINGS.
Driving a rod.



Photograph No. 70.—ROCK SOUNDINGS.
Pulling rod by machine.



Photograph No. 71.—ROCK SOUNDINGS.
Pulling rod with jacks.

1

2

3

4

power is used for operating a large paper mill and for supplying power for a steel plant, city lighting and pumping, and general commercial purposes.

This plant was built by the Lake Superior Power Co. in 1896-1901, and acquired by the present owners in 1916, since when it has been greatly enlarged. It is understood that the present plant is planned for the use of about 20,000 cubic feet per second.

The power outputs and water consumptions given above are only approximate and the gross head is not accurately known, so the efficiency of the plants can only be estimated roughly. At the time when these figures were compiled the total fall at the Soo was about 19 feet. Under this head, with 100 per cent efficiency, 1 cubic foot of water per second would produce 2.16 horsepower. Table No. 13 shows the efficiency of the various plants.

TABLE No. 13.—*Present operation, Sault Ste. Marie power plants.*

Plant.	Water used (cubic feet per second).	Power produced (horsepower).	Horsepower per cubic foot per second.	Over-all efficiency.
				<i>Per cent.</i>
United States Government.....	1 1,030	750	0.73	34
Michigan Northern Power Co.....	30,000	35,000	1.17	54
Great Lakes Power Co.....	12,000	19,000	1.58	73
Total or weighted average.....	43,030	54,750	1.27	59

¹ Including 500 cubic feet per second wasted.

The overall efficiency of the Government plant based on the 530 cubic feet per second actually passing through its turbines is 65 per cent.

In photograph No. 52 is a rear view of the Government power house. No. 53 is of the canal of the Michigan Northern Power Co.

2. CHICAGO DRAINAGE CANAL.

Lockport plant.—At the downstream end of the Chicago Drainage Canal 6,800 cubic feet of water per second are, on the average, used in the production of hydroelectric power. The use of this water is secondary and incidental to its primary use in diluting the sewage of Chicago under the present disposal system. This water is a portion of that already reported in Section B as being diverted from Lake Michigan for sanitary uses.

The general location of the power house is shown on plate No. 4.

After the opening of the Chicago Drainage Canal in 1900, the sanitary district decided to develop the water power which was available at its lower end. As the bed of the Des Plaines River has a steep slope immediately below the controlling works at Lockport, the canal was extended, mainly by rock and earth embankments, 2 miles to the present site of the power house, and the lock and spillways beside it, which are described in Section A of this report. The channel extension has a depth of 24 feet at lowest prevailing stage and a minimum

width of 160 feet. The total drop in water surface from Lake Michigan to the Des Plaines River below the power house is about 45 feet at extreme low water in the Des Plaines River. Several feet of head are lost in the canal, the loss varying with the volume of flow. In the years 1915-1917 the maximum head was 41 feet, the minimum 26, and the mean 34.5 feet. The plant began to generate power in December, 1907.

The power house contains seven units. Each unit has six 54-inch runners placed in pairs on a horizontal shaft submerged in an open flume. Access to the bearings is obtained through steel cofferdams or manhole shafts extending to the surface. These units run at 163 revolutions per minute and are rated at 6,000 horsepower each. The generators are direct connected to the turbines. They generate three-phase alternating current at 6,600 volts, 60 cycles, and are rated at 4,000 kilowatts each. Each generator has three single-phase transformers which raise the voltage to 44,000 volts.

There are three exciters, rated at 350 kilowatts, 250 volts, driven by three small turbines. Space is reserved for the installation of one more of the large units.

Most of the power developed is transmitted to Chicago, where it carries a large street lighting load and a general commercial load. A small amount is distributed at 6,600 volts in the cities of Joliet and Lockport. During the year 1917 the average output was 17,900 horsepower, the maximum output for one half-hour period being 32,100 horsepower.—The average consumption of water by the power plant for the same year was stated by the chief engineer to be 6,850 cubic feet per second, the minimum consumption for any half-hour period being 2,380 cubic feet per second.

The cost of the power-development plant, including the 2-mile extension of the canal, was a little more than \$5,000,000.

Photograph No. 54 is a downstream view of the power house and No. 55 is of the main sector dam beside the power house. Attention is also called to Nos. 12 and 15, given previously.

Joliet plant.—The water passing through the drainage canal power house at Lockport is used again by plants at Joliet and Marseilles. At Joliet the power house contains 32 turbines of various sizes, from 48-inch to 68-inch, driving 10 generators having a total rated capacity of 3,740 kilowatts. Both alternating and direct current is produced and sold for general commercial and lighting loads. The average amount of water used is reported to be 5,250 cubic feet per second and the average power production 3,350 horse power. The dam forms part of the Illinois and Michigan canal system and is owned by the State of Illinois. The head varies from 9 to 13 feet, averaging about 10 feet. It is understood that the water power is leased from the State by the Sanitary District of Chicago. The plant formerly was the property of the Economy Light & Power Co.

The power house is shown on photograph No. 56. A view of the dam has been given as photograph No. 16.

Marseilles plant.—At Marseilles, Ill., there is a dam across the Illinois River owned by the Marseilles Land & Water Power Co., affording a head of about 11 feet. The power is used in a number of plants, partly to generate electricity and partly in the manufacture of coarse grades of paper. Many of the installations are old and of

low efficiency. The capacity of these plants is such that together they use the discharge of the drainage canal and most of the ordinary flow of the Illinois River. The company advertises the production 10,000 horsepower.

Photographs Nos. 57, 58, and 59 show, respectively, the Marseilles Dam, the largest canal, and some of the mills and power houses along the river below the dam.

The three developments described above are the only ones of any importance using the water diverted from Lake Michigan through the Chicago Drainage Canal. The horse power per cubic foot per second obtained at these sites is estimated to be roughly as follows:

Lockport	2.5
Joliet .....	.6
Marseilles .....	.7
Total	3.8

The Ernst Board of Engineers proposed for the Illinois and Des Plaines Rivers a waterway having nine locks with an aggregate low-water lift of 130 feet, including all lifts up to Lake Michigan level. Of this total, 116 feet were available for water power. If this project was developed and modern hydroelectric plants installed, a total of 11 horsepower per cubic foot per second might be obtained.

Ottawa plant.—In addition to the three plants described, there is a very small installation at Ottawa, Ill., taking water from a branch of the Illinois and Michigan Canal. This plant operates eight hours a day, using about 120 cubic feet per second while operating. The head is 28.9 feet. The power developed is probably between 200 and 300 horsepower. The water used may be considered as being furnished partly by the natural flow of Des Plaines River and partly by diversion from Lake Michigan through the drainage canal. As already pointed out, the extreme low-water flow of the Des Plaines above Joliet is only 7 cubic feet per second.

3. WELLAND CANAL.

The diversion from Lake Erie through the Welland Canal for power purposes appears to be approximately 3,400 cubic feet per second. This is a primary use of the water, as it is diverted from the Lake Erie level of the canal before having been used in any manner for the benefit of navigation. In fact it may be said that the diversion is slightly detrimental to navigation in that it increases the small current in the canal.

On plate No. 6 is a map of the Welland Canal, on which is indicated the power plant at De Cew Falls, and showing the old canal from Thorold to Port Dalhousie, along which are located all the other power plants.

A description of power development from the waters of the Welland Canal falls naturally into two parts. The one treats of the diversion of the De Cew Falls plant of the Hamilton Cataract Power, Light & Traction Co. This is a large modern plant, with a capacity of over 50,000 horsepower. Its head is by far the greatest of any plant now using the waters of the Great Lakes. The other part treats of the remaining plants. These are many in number, but of small individual importance, developing 10 to 2,000 horsepower each under heads of from 8 to 23 feet. Most of the installations are old and in-

efficient and many run only intermittently. Their total capacity does not amount to 15,000 horsepower.

De Cew Falls plant.—The De Cew Falls plant is owned by the Hamilton Cataract Power, Light & Traction Co. (Ltd.), which is controlled through stock ownership by the Dominion Power & Transmission Co. (Ltd.). The latter company controls all the electric service companies in the vicinity of Hamilton.

The water used by this company leaves Lake Erie at Port Colborne and flows down the Welland Canal to Allanburg, a distance of about 16 miles. Here it enters the "old" Welland Canal and shortly thereafter leaves that through the "Government measuring weir." Thence it passes through gates into a chain of shallow ponds about 4 miles long, extending to the top of the Niagara escarpment, in the vicinity of De Cew Falls, which is on a small branch of Twelve-mile Creek. At this point is a small fore bay with a spillway and rackhouse. From the rackhouse the water is carried down the slope of the escarpment in seven long steel penstocks, which are laid on the surface of the ground and covered with wooden housings. The oldest one is $7\frac{1}{2}$ feet in diameter and the others are 6 feet each.

The power house at the foot of the escarpment contains two groups of machinery. The older group consists of four horizontal-shaft units, all supplied by the $7\frac{1}{2}$ -foot penstock. Two of these have turbines of Italian make, each driving a 2,000-kilowatt Westinghouse generator. The third has a Voith turbine, and its generator is rated at 1,000 kilowatts. The fourth unit is smaller, being a turbine-driven exciter. The newer group consists of six units, each supplied by one of the 6-foot penstocks. Each consists of a Voith turbine, rated at 8,000 horsepower, and a 6,000-kilovolt-ampere generator, built by the Canadian General Electric Co. Each turbine has a double runner on a horizontal shaft in a single scroll case and double draft tubes. Each unit is controlled by a Voith governor operating wicket gates. Each penstock is provided with a synchronous relief valve actuated by the governor and installed on a short by-pass extending from the penstock at the scroll-case connection to one of the draft tubes. A similar by-pass to the other draft tube is provided with a pressure-bursting plate relief. The current is generated at 2,400 volts, 3-phase, 66 $\frac{2}{3}$ cycles per second, a very unusual frequency.

From the draft tubes the water flows through a tail-bay into Twelvemile Creek, which it follows for $2\frac{1}{2}$ miles to the old Welland Canal level, just below Lock No. 3, at St. Catharines.

Most of the power is sold in Hamilton and its neighborhood. It is transmitted by three transmission lines with steel towers. The transmission voltage is 50,000 volts, and the distance is about 35 miles. In Hamilton is a large steam station, which helps carry the peak loads. At present the daytime load of this plant is about 50,000 horsepower. At night it is approximately 45,000 horsepower, and on Sundays it is somewhat less.

The gross head on this plant is variously given at 260, 263, 264, and 268 feet. The most authoritative statement is probably that of Water Powers of Canada, published in 1911 by the Canadian conservation commission. On page 90 is the statement that this plant is operated "under a static head of 263 feet, and under full load each penstock has an operating head of 256 feet." Presumably this

means the net head on the turbine. From tests of fairly similar machines of the Hydraulic Power Co. at Niagara Falls it would appear that the combined efficiency of the turbine and generators at full load is probably about 82 per cent. The power produced would then be 23.8 horsepower per cubic foot per second. An output of 50,000 horsepower would thus require a diversion of 2,100 cubic feet per second.

This company possesses five leases, which together entitle it to a continuous use of 1,160 cubic feet per second. Out of this quantity it must furnish the city of St. Catharines its water supply, estimated at 25 cubic feet per second. The leases are as follows:

Ontario Government:	Rent per annum.
Dec. 31, 1902, 700 cubic feet per second.....	\$21,000
Mar. 31, 1906, 300 cubic feet per second.....	9,000
Robert Cooper lease, Dec. 15, 1909, 100 cubic feet per second.....	413
Townsend grant, date unknown, 10 cubic feet per second.....	None.
City of St. Catharines' lease, date unknown, 50 cubic feet per second....	500

It appears that the company diverts at least 940 cubic feet per second more than is covered by the leases.

Construction of the plant was begun in 1898 and completed about 1908. This is some time before May 13, 1910, the date on which the boundary waters treaty was proclaimed. It appears from official reports and letters, however, that the plant was not operating at full capacity in 1910 or earlier, and that a substantial increase in the diversion has been made since that date.

Welland River plants.—Of the water that enters the Welland Canal from Lake Erie a certain amount is spilled into the Welland River, part at Welland, and the rest at Port Robinson. Part of this water is or has been used for power development. The 1911 report of the commission of conservation lists one development of 25 horsepower at Port Robinson, and two developments at Welland, one of 60 horsepower and the other of 100 horsepower. In 1918 the amount spilled at these two places was estimated by the Canadian engineers to be 440 cubic feet per second.

Plants along old canal.—About a mile above Thorold, in the side of a short level of the present canal between the guard gates and Lock 25, is a submerged outlet through which a regulated flow is permitted to escape into the old canal. The lower level of this sluice is shown in photograph No. 23. From this point to Port Dalhousie along the old canal there are 25 locks, with a total fall of about 320 feet. Power installations exist at nearly every lock, and there are several on a raceway at Merritton, which is known as the "hydraulic raceway." In 1905 there were 34 leases of water rights along this canal still in existence. Most of these were very old, and had stipulated rentals based on a formerly existing flow of water far less than that then used. In several cases either the rent was not being paid or else some other condition of the lease was not being complied with. The old canal was practically not used at all for navigation, and was being maintained by the Province for the benefit of the water-power interests, at a cost exceeding \$20,000 per annum, while the revenue from rentals to power users was less than \$9,000 per annum. In 1911 there were 24 developments along this reach listed by the conservatism commission.

In 1918 a hasty reconnoissance showed a large number of small water powers. Some were operating regularly, some were apparently

abandoned, while others appeared to have suffered destruction of the plant by fire. There seemed to be 18 developments, used by 13 concerns. The Canadian authorities were evidently without authentic record of the present owners of the leases or of details of the developments. They estimated the total flow through the sluiceway above Thorold at 800 cubic feet per second. Below Lock 3 this flow is augmented by the 2,100 cubic feet per second or thereabout which comes down Twelvemile Creek from the DeCew Falls plant. The entire flow of 2,900 cubic feet per second is available for power development at Lock 2 at St. Catharines and at Lock 1 at Port Dalhousie. The total installed power is perhaps 12,000 horsepower. Inasmuch as 29,000 horsepower or more could be developed continuously with this diversion, it would seem that more than 50 per cent of the value of the diversion was wasted.

To gather data for a detailed report on all of these installations would have been a slow and expensive procedure. In view of the relatively small volume of the diversion involved it was considered that such a report would not have a value commensurate with the labor and expense of compiling it.

Photograph No. 25 shows the point of discharge of Twelvemile Creek into the old Welland Canal. No. 24 shows Lock 3 of the old Welland. No. 60 is of mills developing power near Lock 3. No. 61 is of mills near Lock 2.

TABLE NO. 14.—*Estimated diversions of the Welland Canal, in cubic feet per second.*

Into the Welland River-----	440
Down the old canal-----	800
To the DeCew Falls plant-----	2, 125
Total available for power-----	3, 365
For navigation only-----	1, 100
Total-----	4, 465

The estimated diversions of the Welland Canal are given in table No. 14. Of this about 40 cubic feet per second comes by way of the Port Maitland feeder from the Grand River, a tributary of Lake Erie. The remaining 4,425 comes directly from Lake Erie. Four hundred and forty cubic feet per second enters the Niagara River above the falls by way of the Welland River (Chippawa Creek). The remaining 4,025 enters Lake Ontario at Port Dalhousie.

4. NEW YORK STATE BARGE CANAL.

The present diversion through the New York State Barge Canal of Niagara River waters for power purposes is approximately 500 cubic feet per second, this diversion being covered by permits from the Secretary of War and the New York State superintendent of public works. In addition, power is developed at Lockport from water by-passed around the locks to feed the lower level from Lockport to Lyons. This quantity varies considerably and may reach a maximum of approximately 1,500 cubic feet per second.

A map showing the barge canal routes is given on plate No. 8. On plate No. 6 the location of the route from Niagara River to Lockport is shown on a larger scale. A series of photographs, Nos. 29 to 46, in-

clusive, with descriptive notes beneath, is given by way of illustrating distinctive features of the canal.

In Section A of this report there has already been given a description of the New York State Barge Canal, and an explanation that its highest level is at the western end, being at the same elevation as the Niagara River at Tonawanda and receiving a supply of water from Niagara River at that point. About 500 cubic feet per second is diverted into Eighteenmile Creek at Lockport, and on down the creek, 12 miles to Lake Ontario at Olcott. Whatever part of the remainder of the total diversion from Niagara River is not lost by evaporation or seepage, or by being spilled over wasteways along the route, is eventually discharged down the Oswego River into Lake Ontario.

Power developments at Lockport, N. Y.—At Lockport there are three conduits or channels through which water may be by-passed around the flight of locks, from the upper level to the lower level of the barge canal. One is the waterway of the small hydroelectric plant situated between the old and new flights of locks. This plant belongs to the State and furnishes electric energy for lighting and operating the locks. Another is a tunnel on the north side of the canal, roughly 8 feet wide, 12 feet high, and 1,600 feet long, extending from a point just above the old locks to a gatehouse on the brink of the high bank. From there two penstocks convey the water down to the wheels in the pulp mill of the United Box Board & Paper Co. The tunnel and appurtenances belong to the Hydraulic Race Co. The third passage is a tunnel about 15 feet square and 700 feet long, which is on the south side of the barge canal, abreast of the new locks, and leads from a point just above the new locks to a small high level basin within concrete retaining walls. It belongs to the State and forms part of the State's by-pass for discharging water from upper level to lower level of the barge canal. Gates in the basin control the flow through the two outlets, one of which is the remaining portion of the State's by-pass and consists of a structural steel flume of large diameter, about 250 feet long, extending down to and out over the lower level. The other outlet from the small basin is a surface canal about 20 feet wide, 6 feet deep, and 2,800 feet long, which follows the side of the steep bank. This canal is the property of the Hydraulic Race Co. The drop from upper to lower miter sill of the new locks is 49.16 feet.

The State hydroelectric plant has an installation of two 14-inch water wheels operating under an effective head of 41.7 feet. It is estimated that the maximum possible rate of consumption of water is about 50 cubic feet per second. As each unit is capable of carrying the entire load, and a unit will be operated only when necessary to provide power for locking operations or for lighting, it is evident that the average daily consumption, even for maximum traffic conditions on the canal, will be less than 20 cubic feet per second.

The north tunnel of the Hydraulic Race Co. supplies two double water wheels in the pulp mill of the United Box Board & Paper Co. In 1917 the flow through this tunnel was measured and found to be 407 cubic feet per second. At that time the water level in the barge canal from Tonawanda to Lockport was held up by a dam at Tonawanda with a crest elevation of 570 feet, barge canal datum. The removal of this dam in 1918 brought the level at Tonawanda down to

200 DIVERSION OF WATER FROM GREAT LAKES AND NIAGARA RIVER.

that of the Niagara River, which varies with the stage of Lake Erie at Buffalo. The mean stage of Lake Erie for the years 1860 to 1910, inclusive, was 572.58 United States standard datum. The corresponding stage at Tonawanda is 566.01 United States datum, or 567.14, barge canal datum. As water practically always flowed over and Tonawanda dam, a lowering of a little more than 2.86 feet at the mean stage given is therefore indicated. At the low stage at 565.5, barge canal datum, at Tonawanda, at which the limiting depth of the canal is 12 feet, the lowering of the level is 4½ feet. It is stated that this lowering has unwatered the upper portions of the north tunnel, and thereby reduced its discharging capacity. At 50 per cent efficiency, which seems a reasonable estimate for the installation, the power produced from 200 cubic feet per second of water acting under 50 feet of head is 570 horsepower. The discharge from the water wheels which are fed through the north tunnel may be turned into the lower level of the canal or into a flume discharging into a basin of Eighteenmile Creek at a lower level and north of the canal. The Hydraulic Race Co. has under advisement plans for deepening and widening the upstream half of the tunnel, abandoning the downstream half, and constructing at the middle point a new power station with an installation of two 1,500-horsepower units.

There are six users of power on the south side of the barge canal who draw water from the surface canal of the Hydraulic Race Co., and discharge it into the lower level of the canal. One of these users owns another installation not now in use, but which it is proposed to put into service. Assuming over-all efficiencies for the seven plants under consideration, and assuming also that in each case the maximum amount of power that can be produced is the installed power or the leased or granted power where the installed amount is not known, or the measured amount where it has been measured, it has been computed that the maximum possible present use of water by the seven plants is 773 cubic feet per second and the maximum possible present development of horsepower is 3,078. The name of each user is given in Table No. 15, together with the assumed maximum developable power, assumed over-all efficiency, and computed maximum possible use of water.

TABLE No. 15.—Power developments on south headrace at Lockport, N. Y.

No.	Name of user.	Assumed maximum horsepower.	Assumed percentage efficiency.	Estimated use of water (cubic feet per second).	Remarks.
1	Lockport Light Heat & Power Co.....	{ 1,500 500	{ 80 65	{ 331 136	} Lease.
	Total.....	2,000		467	
2	Grigg Bros. Co.....	75	70	19	Do. Grant and lease.
3	Thompson Milling Co.....	650	80	144	
	Total.....	2,725		680	
4	Trevor Manufacturing Co.....	21	50	8	Lease.
5	Western Block Co.....	135	50	48	Rated.
6	do.....	100	40	45	Measured.
7	Niagara Emery Mills (Inc.).....	97	40	42	Grant.
	Total.....	3,078		773	

It must be understood that the above given efficiencies and quantities of water are rough estimates believed to be sufficiently in accord with the facts for the investigation in hand. The use of water by most of these plants is intermittent and below capacity.

The entire use of water by the Hydraulic Race Co. at present possible is approximately 200 cubic feet per second through the north tunnel and 773 cubic feet per second through the south race, a total of 973 cubic feet per second.

Water power along Eighteenmile Creek.—Of the barge canal spillways on the long level from Lockport to the Genessee River the one having the greatest length of waste weir crest is at Lockport over Eighteenmile Creek, a little less than half a mile below the locks. There are three waste gates, each $3\frac{1}{2}$ feet square, with an estimated discharge capacity of 600 cubic feet per second at full canal. Eighteenmile Creek, which is a very small stream, passes under the barge canal at the spillway in a culvert and flows nearly due north about 12 miles into Lake Ontario 18 miles east of the mouth of Niagara River. Leaving the culvert the creek follows a narrow gorge for about $1\frac{1}{2}$ miles and falls something like 140 feet in this distance. Thence for $6\frac{1}{2}$ miles to the town of Newfane it winds through rather flat country with a fall of 40 feet or thereabouts. From Newfane to the lake, 4 miles, it flows between banks 40 to 50 feet high and falls approximately 70 feet. At present there are six water-power developments along the $1\frac{1}{2}$ -mile reach just north of the canal and two at Newfane. There are also three unused sites, all of which have been used formerly, and one site with 5-foot head, which apparently never was developed. The 12 sites, developed and undeveloped, are listed in Table No. 16.

TABLE NO. 16.—Power sites on Eighteenmile Creek.

No.	Name of owner.	Head (feet).	Installed horse-power	Estimated practicable horse-power installation.	Assumed percentage efficiency.	Estimated water required (cubic feet per second).	Remarks.
1	United Box Board & Paper Co. (L. and T. Houston mill).	30.4	.....	1,400	80	500	Undeveloped.
2	United Box Board & Paper Co.	14.0	1,600	.....	50	750	Developed.
	Total.....	44.4	.....	.....	.....	.....	Alleged head controlled.
3	Lockport Paper Co.....	12.1	550	.....	80	500	New machinery.
4	Niagara Paper Mills.....	9.7	280	.....	65	390	Average horse-power used, 200.
5	Westerman & Co.....	20.5	475	.....	65	320	
6	Fiber Corporation.....	31.4	820	.....	65	355	
7	Electric Smelting & Aluminum Co.	34.2	1,200	.....	70	440	
8	Niagara Farmers Co.....	5.0	.....	.....	.....	.....	No development.
9	Lockport Felt Co. (Horton Mills Site).	9.5	.....	400	75	500	Old development abandoned years ago.
10	Newfane Lumber & Manufacturing Co.	13.7	529	.....	60	570	Including grist mill of Fred Collins & Son.
11	Lockport Felt Co.....	8.9	240	.....	50	475	Leased to Newfane Electric Co.
12	Western New York Water Co.	47.0	.....	2,150	80	500	Undeveloped.

¹ Assumed, not reported.

Through the flat lands the creek has a maximum discharge capacity of about 500 cubic feet per second. The natural low-water flow is negligible, but the flood flows are sufficient when added to a supply of 500 cubic feet per second from the barge canal to cause the creek to overflow its banks through the flat lands and damage farms and property. The State of New York has appropriated \$2,500 for a survey of this portion of the creek, intending to increase the discharge capacity by straightening and widening. The water-power sites listed in the foregoing table follow one another in succession down the creek, each involving the use of the same water but under a new head.

Medina water power.—At Medina, 17 miles east of Lockport along the barge canal, is a spillway having a waste weir 150 feet long. This is second in length of the 13 spillways of the long level. There are also six waste gates, each 3 feet square, having an estimated total discharge capacity of 1,000 cubic feet per second. The spillway is along the south side of the aqueduct which carries the canal over Oak Orchard Creek. Several miles south of the canal there is an extensive swamp area forming the headwaters of the creek. A supply of water from the upstream portion of Tonawanda Creek is brought into Oak Orchard Creek above Medina through a feeder canal several miles long. The combined supply formerly was fed into the old Erie Canal through a short feeder at Medina, but now passes down Oak Orchard Creek. It is a very small quantity of water in dry times. Under the aqueduct the water surface elevation of the creek is approximately 482, or 32 feet below the spillway crest elevation of 514. From there the creek flows in a northeasterly direction $19\frac{1}{2}$ miles to Lake Ontario through a gorge whose banks are 20 to 90 feet high.

The natural descent of the stream is rather rapid at first, and becomes more gradual toward the lake. The 32-foot drop from canal level to creek at the aqueduct is developed on the south side of the canal by S. A. Cook & Co., who use the water intermittently to furnish power for a plant at the site. From the aqueduct to Lake Ontario the Western New York Utilities Co. owns most of the water rights. This company has two dams and power houses, and is now constructing a third dam and power house. The most upstream dam, No. 1, is just north of the aqueduct. The head is 30 feet, and the installation one 450 horsepower wheel. At 65 per cent efficiency the estimated water consumption is 200 cubic feet per second. One mile below Dam No. 1 is Dam No. 2. There is a storage reservoir of about 150 acres behind Dam No. 2, and the full head is 65 feet. The installation is three 900-horsepower units, a total of 2,700 horsepower. At 80 per cent efficiency the water consumption would be 460 cubic feet per second. Fourteen miles downstream from Dam No. 2 at Waterport, $4\frac{1}{2}$ miles upstream from the lake, Dam No. 3 is now being constructed. The head is to be 85 feet, and a pond of approximately 600 acres will be formed, extending upstream more than 4 miles. The full development contemplates three units, each of 2,800-horsepower capacity. At 80 per cent efficiency and full load the three proposed units will require 1,080 cubic feet per second. The total head to be developed by the Western New York Utilities Co. is the sum of the three heads given above, or 180 feet. Between Dam No. 2 and the head of the pond to be formed behind Dam No. 3 is a fall of

about 60 feet in nearly 10 miles. Development of the power in this reach is remotely contemplated.

Other water powers.—At various other spillways of the barge canal, or rather of its predecessor, the Erie Canal, power has been developed in a small way, partly from the spill and partly from the natural flow of the small streams which pass under the canal prism in culverts at these spillways. It is understood that many of these plants have been abandoned, and all of them seem likely to be.

The barge canal crosses the Genesee River at grade in the city of Rochester. It is intended that the canal shall abstract from the river on the east side a quantity of water equal to that contributed on the west side, neither adding to nor subtracting from the river flow. Below this crossing there are four falls in the Genesee River, providing a total head of about 250 feet. This is all developed, but much of it not very efficiently. The total installation of power-developing machinery is 54,850 horsepower.

Beyond the Genesee River none of the water diverted from Niagara River is used in power development, except for lighting and operating locks, until the Oswego River is reached. Here whatever remnant of the original diversion may remain is utilized in the developments on that stream.

The small State hydroelectric power stations along the portion of the Erie branch of the barge canal falling within the basin of the Great Lakes are located at Locks Nos. 34, 33, 29, 28B, 28A, 27, 24, 23, 21, and 20. Power is transmitted from No. 34 to No. 35, from No. 33 to No. 32, from No. 29 to No. 30, and from No. 21 to No. 22. This power is used only for operating and lighting locks. In almost every case the installation consists of two generating units, each having a 50-kilowatt 250-volt direct-current generator. The maximum quantity of water required at any lock probably does not exceed 100 cubic feet per second, and that requirement is intermittent.

Table No. 17 shows the existing power installations on the Oswego River.

TABLE No. 17.—*Power installations on the Oswego River.*

Place.	Total head.	Power installation.
	<i>Feet.</i>	<i>Horsepower.</i>
Phoenix.....	10.2	3,000
Fulton.....	44.8	15,000
Minetto.....	18.0	9,300
Oswego.....	44.6	4,000
Total.....	117.6	31,300

These cover the entire developable head. It has been estimated by a State legislative committee that these heads may be developed to yield 63,800 horsepower. It is of interest to note that because of the construction and operation of the barge canal the Oswego River receives about 50 cubic feet of water per second which was naturally tributary to the Hudson River, and about 35 cubic feet per second naturally tributary to the Susquehanna River.

The flow from Seneca Lake is developed at Waterloo under a head of 14.5 feet, producing 1,000 horsepower, and again at Seneca Falls under a head of 49 feet, producing 3,700 horsepower.

Leases and permits.—Except in the case of Lockport, it appears that no lease has ever been made or permit granted authorizing the use by individuals or corporations of waters of the western part of the Erie Canal or barge canal, from Niagara River on down along the 60-mile level, for power purposes. Certain other users claim rights on the grounds that, having for many years used water which wasted from the canal, and having invested capital for the purpose, they are now entitled to a continuance of this waste, which the State must furnish them. The State has not conceded any such rights, and some time ago warned the users that such waste was not likely to occur from the new barge canal. In the case of Lockport a lease was made January 25, 1826, to Richard Kennedy and Julius H. Hatch, in consideration of an annual payment of \$200 for—

All the surplus waters which without injury to navigation, or security of the canal, may be spared from the canal, at the head of the locks, in the village of Lockport, to be taken and drawn from the canal at such place and in such manner, and to be discharged into the lower level, at such places and in such manner as the said canal commissioners shall from time to time deem most advisable for the security of the canal, and for the convenience of the navigation thereof.

In 1856 the Lockport Hydraulic Co. was incorporated for a 50-year period, and became the assignee of a part of the rights of this lease, which were, in turn, transferred in November, 1907, to the Hydraulic Race Co., which was incorporated to succeed the Lockport Hydraulic Co., and which now owns the rights jointly with others who leased original rights prior to the formation of the Lockport Hydraulic Co. After the lease had been in existence and the rent paid for 82 years the canal board, on December 31, 1908, canceled the lease in the name of the Hydraulic Race Co., intending that water power at the locks should be used or leased on different terms and under different conditions after the reconstruction of the canal and locks. Thereafter the State comptroller refused for six successive years to accept the annual rent offered. In January, 1915, the courts sustained the validity of the lease and granted a writ of mandamus compelling the comptroller to accept the rents. Under date of September 1, 1896, the city of Lockport obtained a permit to construct a channel for the purpose of taking surplus water from the canal, but this was canceled February 2, 1897.

On August 16, 1907, the Secretary of War granted to the Lockport Hydraulic Co. a revocable permit—

To divert water of the Niagara River and its tributaries from the Erie Canal at Lockport, N. Y., above the locks, for power purposes, not exceeding 500 cubic feet per second.

It was to be distinctly understood that the water so diverted should be returned to the canal below the locks, and that this permit should inure to the benefit of all persons and corporations then using said water for power purposes, whether lessees of the applicant or having the right to be furnished by it with water, and including the persons or corporations then diverting water from the Erie Canal at Eighteenmile Creek, Middleport, Medina, Eagle Harbor, Albion, Holley, and other places. It was stipulated that no right was to be under-

stood as conferred without the consent of the State of New York, and that the permit was subject to any and all regulations and conditions to be imposed by the State. It was understood that the Lockport Hydraulic Co. was diverting 1,000 cubic feet per second at the time, 500 cubic feet per second of which was required for navigation purposes below the locks, and 500 cubic feet per second of which was being used by persons and corporations located as stated above. The purpose of the grant, as in the case of the permits issued on the same day to the Niagara Falls Power Co. and the Niagara Falls Hydraulic Power & Manufacturing Co., presumably was to prevent the grantees from sustaining loss and not to provide for any future development not then actually commenced. Two questions have since arisen. The first was whether or not the permit which was made out to the Lockport Hydraulic Co. could be assigned to the successor, the Hydraulic Race Co.

The second was in regard to the construction of the permit in case more than 500 cubic feet per second of water should be diverted for navigation uses in the canal. It had been estimated by barge-canal engineers that the new canal would require 1,237 cubic feet per second. The opinion was expressed that the 500 cubic feet per second granted by the Secretary of War was to be diverted only in such part as was necessary to make the entire diversion around the locks 1,000 cubic feet per second. Thus in case 1,000 or more cubic feet per second were diverted for navigation purposes there would be none of the Federal 500 cubic feet per second diverted, and although the Hydraulic Race Co. would not suffer, being so situated between upper and lower canal levels as to develop power from water by-passed either for power or navigation needs, yet the users of water power on Eighteenmile Creek and at other places along the lower level would be cut off, and the purpose of the permit would, to that extent, be frustrated. Both these questions were passed upon by the Chief of Engineers in March, 1911, and his opinion, concurred in by the Secretary of War and the Judge Advocate General, was that the grant did pertain to the Hydraulic Race Co., and that it should be construed by conferring the right to divert 500 cubic feet per second independent of the amount required for navigation purposes. The permit by the Secretary of War has been extended from time to time, the last permit being dated July 1, 1918.

The State of New York granted to the Lockport and Newfane Mill Owners Association, on November 25, 1913, a revocable permit to divert from the Niagara River through the barge canal to Lockport and into Eighteenmile Creek the 500 cubic feet per second of water covered by the Federal permit, the association to pay \$7,500 per year to the State for the privilege of using the canal as a raceway. The permit provides for pro rata deductions from the payment for any period of time over one day that the State fails to deliver the water. Provision is also made that the association shall pay the cost of maintaining an inspector of the works involved when the superintendent of public works so directs, and also all damages arising from the diversion of this water. Practically all the manufacturers located along Eighteenmile Creek are members of this association, and the Hydraulic Race Co. is a member. The proportion of the \$7,500 paid by each member is the ratio of the head of that

member's plant to the total developable head. The water users at Medina and other points beyond Lockport, not being members of the Lockport and Newfane Mill Owners Association (Inc.), derive no benefit from this permit.

During the period from 1910 to 1918 the State was engaged in altering and improving the western end of the Erie Canal to make it a part of the new barge canal system. This work included removing one of the old flights of five locks at Lockport and building a new flight of two larger locks on the same site, deepening and widening the canal prism, and constructing new bridges, walls, aqueducts, and other structures. In order to carry on this work to advantage it was necessary to restrict the use of the canal for several years. At times traffic was completely suspended and portions of the lower level were dry. The water power users at Lockport, Medina, and elsewhere were seriously affected by the reconstruction. By means of a temporary dam constructed across the canal near Exchange Street, Lockport, at the expense of the Lockport and Newfane Mill Owners Association, and maintained by them during the closed season of navigation, it was possible for water-power users at Lockport and on Eighteenmile Creek to operate considerably more during several seasons than they otherwise would have been able, while construction work progressed on the lower level.

Records kept by the Fiber Corporation show that in 1917 the flow down Eighteenmile Creek was 500 cubic feet per second on 137 days, nothing on 20 days, and averaged 270 cubic feet per second on the remaining days. Supposedly the manufacturers along the creek have since been able to get the full 500 cubic feet per second permitted whenever they cared to use it. At times of storms or spring run-off, it is necessary to reduce this quantity so that the total discharge down the creek shall not exceed 500 cubic feet per second, as otherwise the low lying farm lands may be damaged by flood.

It has been asserted by some users of water power at Lockport that a more efficient use of water diverted from Niagara River for power purposes can be made by routing them via barge canal to Lockport, and Eighteenmile Creek to Olcott, than at Niagara Falls. The total fall in water surface from Tonawanda to Lake Ontario is 4 feet greater than it is from Grass Island, at the intake of the Niagara Falls Power Co. to Lake Ontario; but 1.5 feet of this difference is lost getting the water to Lockport, leaving a net gain of only 2.5 feet. This difference is soon lost in getting the water from one plant to the next down Eighteenmile Creek. Any practicable future development along the creek would involve similar losses which would total up to a sum sufficiently large to make the net available head considerably less than at Niagara Falls. The total developable head at Lockport and Eighteenmile Creek is stated to be 286.5 feet, and this appears to be a liberal estimate. The members of the Lockport and Newfane Mill Owners Association seem anxious to develop this head efficiently if assured of a reasonably constant supply of water. At Niagara Falls a head of 304 feet is readily developable. The total head at present developed and used is 212 feet at Niagara Falls, and less than 175 at Lockport and Eighteenmile Creek. It has been stated that difficulty with ice caused more power interruptions at Niagara Falls than at Lockport. Even if so,

the argument does not carry much weight because on the average for a number of years the power loss from ice troubles is small at Niagara Falls.

5. BLACK ROCK CANAL.

No water diverted down the Black Rock Canal is now used for power purposes. In the early days of the canal there were two grist mills near the present Black Rock Lock, which operated under a head of about 5 feet. These were abandoned many years ago. Until 1918 the water used from the Erie Canal for power at Lockport, N. Y., and on down the 60-mile level was diverted from Lake Erie through the Black Rock Canal into the Erie Canal at Buffalo.

6. CANADIAN AND UNITED STATES POWER PLANTS AT NIAGARA FALLS.

The present diversions of Niagara River water for power development at Niagara Falls are on the United States side, about 17,600 cubic feet per second, and on the Canadian side probably about 33,300. This gives a total for both sides of 50,900 cubic feet per second. This water is diverted from the river not more than 1½ miles above the Falls and returned to the river within less than a mile of the foot of the Falls.

Developments are now in progress on both sides of the river. That on the United States side is at the hydraulic plant of the Niagara Falls Power Co. It will make possible the use of the full 19,500 cubic feet per second allotted this company, and leave considerable reserve capacity in addition. On the Canadian side there are two developments under way. One is an extension of the plant of the Ontario Power Co., now owned by the Hydro-Electric Power Commission of Ontario, which it is estimated will increase the water consumption of that plant approximately 2,100 cubic feet per second. The other is an entirely new development of the entire head of the Falls and rapids, designed to divert 10,000 cubic feet of water per second.

Reference is here made to the description of Niagara River in Section A of this report, to Plates Nos. 13 and 14, and to the photographs of Falls and rapids accompanying Appendix C.

Limitations on the use of water.—The period from 1890 to 1906 was a time of great waterpower development at Niagara Falls. Within that period all the present powerhouses were begun. A number of other development schemes were advanced and several companies were chartered. The sum of the diversions proposed by these companies amounted to a very considerable portion of the whole flow of the river. It was felt that such unregulated appropriation of the water of the Falls might well cause irremedial damage to their scenic beauty and a widespread agitation arose to prevent such an occurrence. At the request of Congress the International Waterways Commission made an investigation and recommended that the diversions be limited by legislation or treaty.

On June 29, 1906, the Burton Act was passed. This provided for the issuance by the Secretary of War of permits of the following four classes:

First. Permits to divert water from the Niagara River on the American side to present users to an aggregate not exceeding 15,600

cubic feet per second, or 8,600 cubic feet per second to one company.

Second. Revocable permits to divert additional water from the Niagara River on the American side to such amount, if any, as shall not injure the river as a navigable stream or as a boundary stream, and shall not injure the scenic grandeur of Niagara Falls, and not until the 15,600 cubic feet allotted has been used for six months.

Third. Permits to transmit electrical power from Canada into the United States to the aggregate amount of 160,000 horsepower.

Fourth. Revocable permits for the transmission of additional electrical power from Canada into the United States, but in no case, together with the 160,000 horsepower mentioned above and the amount generated and used in Canada, to exceed a total of 350,000 horsepower.

In accordance with the provisions of this act the Secretary of War granted permits of the first and third types mentioned above, as follows:

Diversion of water from Niagara River:		Cubic feet per second.
Aug. 16, 1907. To the Niagara Falls Power Co.	-----	8,600
Aug. 16, 1907. To the Niagara Falls Hydraulic Power & Manufacturing Co. (later the Hydraulic Power Co.)	-----	6,500
Aug. 16, 1907. To the Lockport Hydraulic Co. (later the Hydraulic Race Co.)	-----	500
Total	-----	15,600
Importation of electric energy from Canada:		Horsepower.
Aug. 16, 1907. To the Ontario Power Co.	-----	60,000
Aug. 16, 1907. To the Canadian Niagara Power Co.	-----	52,500
Aug. 17, 1907. To the Electrical Development Co. (now Toronto Power Co.)	-----	46,000
Total	-----	158,500

A reservation of 1,500 horsepower to be imported was made for the International Railway Co., but no permit was ever granted, because the company was unable to obtain the necessary Canadian license.

The quantities of water stipulated were such as the respective companies considered necessary for operating to full capacity the plants then completed or actually under construction.

The Burton Act would have expired by limitation on June 29, 1909, but it was extended to June 29, 1911, by joint resolution of Congress, approved March 3, 1909. On June 29, 1911, the act expired by limitation, but it was extended by joint resolution on August 22, 1911; expired again March 1, 1912; was extended again April 5, 1912; and expired finally March 4, 1913.

Section 4 of the Burton Act requested the President to negotiate a treaty with Great Britain on this subject. This was done, and the treaty was ratified May 5, 1910. By its provisions this treaty was to remain in force for five years from date of ratification, and thereafter until terminated by 12 months' written notice from either party. No such notice has been given.

Article 5 of the treaty makes the following stipulations respecting the waters of Niagara River:

ARTICLE V.

The high contracting parties agree that it is expedient to limit the diversion of waters from the Niagara River so that the level of Lake Erie and the flow of the stream shall not be appreciably affected. It is the desire of both parties to accomplish this object with the least possible injury to investments which have already been made in the construction of power plants on the United States side of the river under grants of authority from the State of New York, and on the Canadian side of the river under licenses authorized by the Dominion of Canada and the Province of Ontario.

So long as this treaty shall remain in force no diversion of the Niagara River above the Falls from the natural course and stream thereof shall be permitted except for the purposes and to the extent hereinafter provided.

The United States may authorize and permit the diversion within the State of New York of the waters of the said river above the Falls of Niagara, for power purposes, not exceeding in the aggregate a daily diversion at the rate of 20,000 cubic feet of water per second.

The United Kingdom, by the Dominion of Canada, or the Province of Ontario, may authorize and permit the diversion within the Province of Ontario of the waters of said river above the Falls of Niagara, for power purposes, not exceeding in the aggregate a daily diversion at the rate of 36,000 cubic feet of water per second.

The prohibitions of this article shall not apply to the diversions of water for sanitary or domestic purposes or for the service of canals for the purposes of navigation.

The treaty also created an International Joint Commission, composed of three commissioners from each country, for the settlement of minor difficulties concerning boundary waters and kindred matters and to investigate and report upon such questions regarding boundary waters as might from time to time be referred to it.

During the operation of the Burton Act the permits of the various companies were interpreted to limit the maximum diversion at any moment. When the Burton Act expired on March 4, 1913, the companies ran as they pleased, and somewhat in excess of the old permits, until it was decided that the Secretary of War had authority to limit the American diversions under sections 10 and 12 of the river and harbor act of March 3, 1899. The companies were informed by the Chief of Engineers on July 19, 1913, that—

For the present no objection is being made by the War Department of existing diversions so long as the daily average does not exceed that of the permits and diversion limits which existed last year under the Burton Act.

The companies continued their operations on the basis of this information until May 28, 1914, when they were notified by the Secretary of War that the maximum limitations of diversions were interpreted as relating not to the daily average quantity diverted, but to the quantity diverted at any moment. This status continued up to December, 1915.

In the winter of 1915-16 the growing demand for electric power in Buffalo caused a serious shortage of power there during the evening hours. The Buffalo General Electric Co. was building a new steam plant to relieve the situation, but it could not begin supplying power from this station for some months. No formal permit for additional diversion was granted, but because of the emergency the Secretary of War decided to raise no objection to an excess diversion by the Niagara Falls Power Co. not to exceed 1,000 cubic feet per second between the hours of 4 p. m. and 7 p. m. during the months of December, 1915, and January and February, 1916.

During the following spring the power shortage in Buffalo became worse and on May 25, 1916, the Secretary of War permitted the diversion of the Niagara Falls Power Co. to be increased sufficiently to meet the demands of existing customers of the Buffalo General Electric Co., which could not otherwise be supplied. It was provided that such power should only be furnished when it was indispensably necessary, and should not exceed 12,000 horsepower in addition to that generated under the old permit. This diversion was to be permitted only until December 31, 1916. The privilege was made use of from July 26, 1916, to December 31, 1916.

On January 19, 1917, a joint resolution of Congress was approved, authorizing the Secretary of War to issue revocable permits for the additional diversion of water. Permits were issued to the Hydraulic Power Co. for 8,785 cubic feet per second and to the Niagara Falls Power Co. for 10,000 cubic feet per second. These increases of the diversion were made because of the shortage of power in the Niagara frontier district, and the great importance of the munitions industries dependent upon Niagara power. They expired on June 30, 1917, but were extended one year by another joint resolution. On July 1, 1918, the Secretary of War issued new permits under authority of a joint resolution of June 29, 1918. These gave 9,500 cubic feet per second to the Hydraulic Power Co. and 10,000 cubic feet per second to the Niagara Falls Power Co. until July 1, 1919. Under these permits, and the additional one allotting 500 cubic feet per second to the Hydraulic Race Co. of Lockport, the whole 20,000 cubic feet per second authorized by the treaty is made available, and the companies are able to utilize the full capacity of their plants.

When the first permits were granted in 1906 the Niagara Falls Power Co., with its tenant, the International Paper Co., was already using nearly the full 8,600 cubic feet per second granted, and continued to use about this amount until 1916, when it was increased by temporary permits. For the last two years the diversion by this company has usually been between 9,000 and 10,000 cubic feet per second.

In 1906 the Hydraulic Power Co. and its tenants was diverting only about 2,500 cubic feet per second. As the installation of new units proceeded this amount was gradually increased until by the end of 1911 nearly the full 6,500 of their permit was being used. The diversion continued to exceed 6,000 until the temporary permits of January, 1917, allowed it to attain its present value of nearly 9,000 cubic feet per second.

Supervision of the importation of electrical energy from Canada terminated with the final expiration of the Burton Act.

In Canada there has been no legislation limiting the diversion on that side.

Canadian Niagara Power Co.—This company is controlled by the Niagara Falls Power Co., which owns all the bonds and all but a few shares of the stock. The capital stock is \$3,000,000, of which \$2,939,600 is outstanding. The bonded debt is 6,480,000, covered by three issues of 6 per cent debenture bonds. The diversion from Niagara River by this company is estimated to be 9,600 cubic feet per second.

The company operates under a lease from the Queen Victoria Niagara Falls Park Commissioners, dated May 1, 1899, having a life of 50 years and renewable for three further periods of 20 years each, with the provision that the lieutenant governor in council may require a fourth renewal for a term of 20 years. The company is bound by the lease to pay an annual rental of \$15,000 for generating any power up to 10,000 horsepower, \$1 per horsepower for all power between 10,000 and 20,000 horsepower, 75 cents per horsepower for all power between 20,000 and 30,000 horsepower, and 50 cents per horsepower for all power above 30,000 horsepower. Thus, for an output of 100,000 horsepower, which is approximately the quantity now generated, the annual rental is 67½ cents per horsepower per annum. The rentals may be adjusted at each renewal of the lease.

The plant of the Canadian Niagara Power Co. was the first hydro-electric development on the Canadian side at Niagara Falls. As early as 1889 the American capitalists interested in the Niagara Falls Power Co. made unsuccessful overtures to the Commissioners of Queen Victoria Niagara Falls Park. Later, English capitalists secured for \$10,000 an option to develop power in the park, and renewed the option for a second year for \$10,000. The option finally expired March 1, 1892. English and American capitalists then combined and secured from the park commissioners on April 7, 1892, the exclusive right to utilize the waters of the Niagara River for power development within the limits of the park. During the same month the Ontario Legislature confirmed this agreement and incorporated the Canadian Niagara Power Co. At a later date the legislature passed an act conferring on the park commissioners authority to negotiate with the company for the surrender of the exclusive privileges granted; and on July 15, 1899, the company abandoned the exclusive rights in return for certain concessions. Still further restrictions were placed upon the company's operations on June 19, 1901, when it obtained an extension of the time limit within which to construct its works.

Under its statutory rights the company is not limited in its production of power, nor as to the amount of water which it may withdraw from the river. Its plans, however, are subject to the approval of the park commissioners, and those already approved call for an installation of 11 units of 11,000 horsepower, nominal capacity, each operating under a head of approximately 141 feet. On the basis of the nominal power of such an installation, and under the further assumption that one unit would always be held as a spare, it was computed in the year 1906, or thereabouts, that the probable consumption of water would be 9,500 cubic feet per second.

Construction of the plant was commenced in 1901. The first power was produced in January, 1905, and the tenth unit, the last to be installed, was placed in service in 1916.

The location and general layout of this plant is shown on the map on Plate No. 13.

In general the main features of this plant are very similar to those of the plant of the Niagara Falls Power Co. There is a short fore bay leading to a power house 600 feet long by 110 feet wide. Under the power house and running nearly its entire length, is a narrow, deep wheel pit. From the bottom of this pit, at one end, a

tailrace tunnel about 2,200 feet long leads to the Maid-of-the-Mist pool beyond the Falls.

The water for this plant is diverted at the Canadian shore of the rapids, about a quarter of a mile upstream from the Horseshoe Falls, through an opening about 370 feet wide and 15 feet deep. This opening has recently been fitted with a set of submerged arches to keep out ice. The fore bay has a length of 270 feet and a depth of 14 or 15 feet. From the entrance described above it narrows to a width of 282 feet, at which point it is crossed by a highway and electric railway bridge. It then widens to a width of 526 feet along the face of the power house. A row of submerged arches in the wall of the power house admits the water to a small inclosed fore bay within the building. Here it passes through racks and enters the 10 penstocks. From the northwest corner of the outer fore bay an ice run leads to the river.

The hydraulic machinery is under the power house in a wheel pit 564 feet long and 18 feet wide, with a mean depth of 160 feet. The penstocks are of steel, 10.2 feet in diameter. They enter the pit almost horizontally, and descend vertically down the pit to the turbine deck, where they make a right angled turn and enter the turbines 116 feet below the fore bay level.

The 10 turbines are of three different types. The five constituting the original installation are inward-flow wheels with double runners. The two runners are on a common vertical shaft and discharge into a cast-iron draft chest between them from which the two draft tubes lead. The runners are of bronze and are 5 feet 4 inches in diameter. The consumption of water is regulated by cylinder gates. Each turbine has two draft tubes 5 feet 3 inches in diameter and about 50 feet long. These units are rated at 10,000 horsepower each.

Two other units are of similar design but are rated at 12,500 horsepower, and are each provided with three draft tubes. The remaining three units, also rated at 12,500 horsepower, are of more modern design, with single runners and single draft tubes. These last five turbines have scroll cases and cylinder gates.

The tailrace formed by the bottom of the wheel pit is 18 feet wide and about 32 feet deep at the north end, from which the bottom slants up on a 3 per cent grade to the south. The draft tubes enter its sides at an angle of 45° a few feet above the bottom. At the north end is a gate for use when only a few units are operating to prevent the draft tubes becoming unsealed.

From the north end of the tail race the water is carried away by a tail-race tunnel 2,164 feet long. Its cross-section is of the horseshoe type, 25 feet high and 18 feet 10 inches greatest width. It is lined with concrete with a facing of brick. The tunnel has a descending grade of 7 feet per 1,000, except near the portal where it falls 11.2 feet in 103 feet by a reverse vertical curve with a radius of 248 feet. The greater part of this portion is lined with granite blocks. The mean velocity through this tunnel is about 24 feet per second. The portal is at the water surface in the Maid-of-the-Mist Pool a few hundred feet from the Canadian end of the Horseshoe Fall.

The generators are of the vertical shaft type with internal revolving fields. They are connected with the turbine by hollow steel shafts 3 feet 4 inches inside diameter, except at the bearings, where the

shafts are solid and of smaller diameter. The first five generators are rated at 10,000 horsepower each, and the other five at 12,500 horsepower each. They operate at 25 cycles per second.

Alcoves, or chambers, in the rock beside the wheel pit at the elevation of the turbines contain the eight exciters, rated at 267 horsepower each. A similar chamber contains a pumping system for supplying cooling water to the transformers.

The oil switches and other auxiliaries are operated electrically from a switchboard in the power house. The power house is connected by an underground conduit line to a large transformer house about 2,000 feet south of the power house. This contains 15 transformers rated at 1,675 horsepower each, and 6 rated at 5,850 horsepower each. These can be connected to give either 22,000, 33,000, 38,500, or 57,300 volts. The output of the transformer station is used chiefly for transmission to Buffalo at 22,000 volts over a pole line 16 miles long, including a river crossing of 2,193 feet span between Fort Erie, Ontario, and Buffalo. Another underground conduit line crosses the Upper Steel Arch Bridge to Niagara Falls, N. Y., and connects with the Niagara plant of the Niagara Falls Power Co.

This plant and stations 1 and 2 of the Niagara Falls Power Co. are operated as a unit, and machines in the different plants may be run in parallel. The Canadian plant is now generating about 100,000 horsepower, of which a little less than one-half is imported into the United States either by the transmission line to Buffalo or by the 12,000-volt line across the bridge at Niagara Falls. A large part of the power which does not come to the United States is sold to the Hydro-Electric Power Commission of Ontario.

The gross head on this plant is about 173 feet at mean stage. As the plant is now operated about 43 feet of this is lost in the tunnel. From the best data available it appears that this plant is now producing about 100,000 horsepower from about 9,600 cubic feet of water per second. That would indicate the production of 10.4 horsepower per cubic foot per second, or an over-all efficiency of 53 per cent.

Considerable trouble with ice is experienced nearly every winter, and the company maintains an electric tug in the forebay to keep the ice broken up.

The importation of power from this plant into the United States began on August 1, 1905. The average amount imported that year was about 4,000 horsepower. The next year it was 12,000. From then it increased gradually, reaching 61,000 horsepower in 1913, and about 62,000 in 1915. In 1916 the exportation was restricted by Canada so that the average in 1917 had fallen to 37,000 horsepower. In November, 1918, it was about 40,000 horsepower.

Ontario Power Co.—The diversion of water from Niagara River by the Ontario Power Co. is estimated to be 11,200 cubic feet per second. Extensions to the plant now well under way will increase the diversion to a quantity estimated to be 13,300 cubic feet per second. This company is controlled by the Hydro-Electric Power Commission of Ontario, which owns 90 per cent of the stock. The authorized capital stock is \$15,000,000, but the outstanding stock is only \$10,000,000. The outstanding bonded debt is \$12,678,000 as against \$15,000,000 authorized.

This company came into existence in 1887 under the name of "Canadian Power Co.," having been incorporated by the Ontario Legislature. Its name was changed to Ontario Power Co. in 1899. The privileges granted it included—

Full power to construct, equip, maintain, and operate a canal and hydraulic tunnel from some point in the Welland River at or near its conjunction with the Niagara River to a point or points on the west bank of the Niagara River about or south of the Whirlpool, and from a point or points in the Niagara River at or immediately south of the head of the rapids near the Welland River to a point or points on the west bank of the Niagara River about or south of Clark Hill.

None of the works authorized were to be constructed and none of the powers given exercised within the limits of Queen Victoria Niagara Falls Park, except with the consent of the lieutenant governor in council and the park commissioners. It should be pointed out that the park then extended upstream only to include the Dufferin Islands.

On April 11, 1900, the first agreement with the park commissioners was made, providing for a double development, the water being diverted from Welland River through a canal to a power house in the park, where it would be used under 40 feet of head, and conducted from that point partly in an open canal and partly underground to a power house in the gorge below the Falls. By a second agreement, dated June 28, 1902, the rights of the first agreement were for the most part surrendered, and provision was made for conducting water from Welland and Niagara Rivers underground. This last agreement specified the general terms of the license, which was granted April 1, 1900, and which provides for a yearly rental of \$30,000, with \$1 per horsepower per annum additional for any power generated above 20,000 horsepower and up to 30,000 horsepower, 75 cents per horsepower per annum for power from 30,000 to 40,000, and 50 cents per annum for each horsepower above 40,000. The lease covers a term of 50 years, with option of three renewals of 20 years each, and provision to compel a further 20-year period of operation by the company. The rent may be adjusted at each renewal.

On August 7, 1902, and subsequently the same year upon submittal of plans, approval was given to construct a plant having three underground conduits each 18 feet in diameter, conducting water from Niagara River at the Dufferin Islands to a power house in the gorge below the Falls.

On August 1, 1917, the Hydro-Electric Power Commission of Ontario took possession of the plant upon purchase of 90,000 shares of the capital stock at \$80 a share (par value \$100) and upon agreement to assume the bond liability of this and certain subsidiary companies, the total of which was stated in the press to be \$14,669,000. Payment for the stock was made in 4 per cent, 40 year, bonds of the Hydro-Electric Commission, guaranteed by the Province of Ontario.

In the agreements the amount of water which the company may divert is not specified, nor the amount of power which may be generated. The plans are said to call for 22 units of 10,000 horsepower each, operating under a total head of 180 feet. The reports of the park commissions, and other printed statements set the approval plans at 180,000 horsepower, 60,000 from each of the three conduits. In 1906 or earlier the ultimate diversion of water required was variously computed to be 11,700 cubic feet per second and 12,000 cubic feet per second.

The intake of this plant is situated at the Dufferin Islands about 5,000 feet above the Horseshoe Falls, and the power house is in the Gorge about 1,000 feet below them. The essential feature of the intake is a submerged weir or diverter extending into the river at the crest of the first cascade. This is a curved concrete dam about 700 feet long, with its crest at elevation 553, corresponding to the extreme low stage of the river at this point. The water enters the outer fore bay between the shore and the outer end of this weir. This opening is protected by an ice diverter consisting of a submerged curtain wall making an angle of 45° with the original current in the river. The bottom of this curtain wall is about 5 feet below low water and 6 feet above the bottom of the intake. It is 596 feet long, and is supported on concrete piers which leave between them 25 openings each 6 feet high and 20 feet wide. Gates are provided for closing these openings and draining the fore bay.

The outer fore bay is about 800 feet long and its width tapers from 600 to 320 feet, its center line following a curve through an angle of about 80° . At its inner end is the rack house, parallel with the shore. This is 320 feet long, and is protected by a similar curtain wall 4 feet below low water and provided with 16 openings each 14 feet high and $18\frac{1}{2}$ feet long. These openings are guarded by racks. To insure a current along this curtain wall to carry away ice, the end of the weir next to the rack house has its first 50 feet cut down 4 feet and its next 50 feet cut down 2 feet below the rest of the crest.

The inner fore bay lies between the rack house and the gatehouse. It is 250 feet long and tapers in width from 320 to 120 feet, its center line curving through about 90° . At its lower end is the gatehouse which is provided with the head works for three 18-foot pipes. The pipe or conduit entrances are closed by large Stoney gates 18 feet square. The entrance is guarded by coarse racks and a small ice run.

The first conduit was of steel. It was circular, 18 feet in diameter, one-half inch thick, and 6,180 feet long from the gatehouse to the first penstock. It had a fall of 28 feet and was designed to carry about 4,000 cubic feet of water per second. It was incased in concrete at the time the second conduit was laid. The conduit was laid in open cut through the park and covered with a few feet of earth. The second pipe is parallel to the first. It is of reinforced concrete of a peculiar oblate cross section equivalent in area to an 18-foot circle, and 18 inches thick. The third 18-foot pipe provided in the original design has never been installed, but a $13\frac{1}{2}$ -foot wood stave pipe of Oregon fir, 4 inches thick, has been built in its place recently as a temporary measure.

From the lower end of the steel pipe seven steel penstocks 9 feet in diameter descend vertically through shafts in the rock. They are controlled by large, horizontal gate valves in a gallery under the conduit. These penstocks descend vertically to the level of the basement of the power house, make a right-angled turn on a radius of 18 feet, and extend horizontally into the power house. Two smaller penstocks, each 30 inches in diameter, reach from the conduit to the power house in a straight line through an inclined tunnel, which also carries the cable ducts connecting the power house and the transformer house. At the end of the conduit is a small open surge basin or spillway provided with a waste tunnel.

In similar manner seven large penstocks and two small ones lead from the second conduit to the power house. There is also a gate valve and connection by which penstock No. 7 can be fed from the second conduit instead of the first. Penstocks No. 13 and No. 14 and the two small penstocks are controlled by "Johnson valves" instead of gate valves. No. 13 and No. 14 can also be connected to the new wood-stave conduit. The end of the second conduit leads to a "Johnson differential surge tank" with waste tunnel. For the wood-stave conduit a steel surge tank 50 feet in diameter and 80 feet high has been erected in the park.

The power house is a concrete building in the Gorge. It is 77 feet wide and about 650 feet long. As originally designed it was to have 18 units of 10,000 horsepower each and 4 exciters. It now has 16 units, the last two of which are in process of installation. The first three are rated at 10,000 horsepower each, the next four at 12,000 horsepower each, and the next seven at 14,000 horsepower each. They are all of the same general type, though made by different manufacturers and having different details. Each unit consists of two Francis turbines and a generator mounted on a common horizontal shaft. The turbines are supplied with water by ascending branches from the penstocks below them. They have scroll cases and wicket gates and discharge through a common draft tube between them into tailraces under the power house. The draft tubes are 10 feet in diameter, and the tailraces at their outer end are vaulted passages 5½ feet high and 20 feet wide. They discharge over a weir into the Maid of the Mist Pool. At full load the elevation of the tail-water above the weirs is about 353. The generators, which are of the internal-revolving field type, are at the river ends of the horizontal shafts. They operate at 187½ revolutions per minute and produce three-phase alternating current at 25 cycles, 12,000 volts.

The two small machines, fed from the first conduit and originally installed as exciters, are now used to generate direct current for running elevators and for other station service. Excitation is provided by a rather unusual system. The two small penstocks from the second pipe supply water to two small horizontal-shaft turbines, each of 1,600 horsepower. Each turbine is direct connected to a small alternator, an induction motor, and an exciter for the alternator. The alternators supply current to 14 small motor-generator sets, one beside each large generator. These supply the direct current to excite the fields of their respective generators. Each direct-current generator of the motor-generator sets is connected up permanently to the field of its corresponding main generator, and its voltage is maintained automatically by a Tirrell regulator in the operating room, which is shunted across the field of the small machine. The regulator connections provide regulation of the power factor of the main generator also. The induction motor on each service unit can be connected to low-voltage secondary mains leading from transformers on the main line. It was intended originally that the motor should be in circuit customarily, thus "floating on the line," to be ready to pick up the service unit load in case the turbine failed, and also to steady the turbine, and thus improve the speed control. In practice it has been found more satisfactory to switch the motors off from the line. Thus their rotors merely rotate idly on the shafts.

The station is operated from a switchboard in the transformer house. This is a large building on top of the bluff. It is about 550 feet behind the powerhouse and 255 feet above it. It contains a large installation of transformers and is the starting point of the transmission lines. The transmission is at various voltage from 12,000 to 110,000. The most important lines are those of the Hydro-Electric Power Commission, and the Niagara, Lockport & Ontario Power Co. The first runs primarily to Hamilton and Toronto but distributes much power in neighboring parts of Ontario, running as far west as Windsor. For the second line the Ontario Power Co. takes the power about 5 miles down the river and across the lower gorge below the Devils Hole. Here it is delivered to the Niagara, Lockport & Ontario Power Co. in a building on the American side. The latter company transmits it to Lockport, Rochester, Syracuse, and other points. These two customers each take about one-third of the output of the plant. The remainder is distributed to near-by consumers on both sides of the river.

This plant is now producing about 163,000 horsepower, of which about 50,000 horsepower is imported into the United States. The gross head on this plant from the river at the intake to the Maid-of-the-Mist Pool is about 215 feet. From the best data available it appears that 11,200 cubic feet of water per second are used to generate 163,000 horsepower. This is an output of 14.6 horsepower per cubic foot per second and an over-all efficiency of 60 per cent. This is the most efficient of the Canadian plants at Niagara Falls, and it develops more power than any other hydroelectric station at the Falls. It began to produce in November, 1905.

To afford relief during the great shortage of power caused by the development of the munitions industries in the Niagara district the company is now installing two temporary units. These machines were built for the plant of the Aluminum Co. of America on the Yadkin River. They are very similar to the other units in this station and are expected to develop about 15,000 horsepower each. The output of the machines on conduit No. 2 will be increased by the paralleling of that conduit with the new one, and the total increase in the capacity of the plant will probably be between 40,000 and 50,000 horsepower. This will increase the total use of water to at least 13,300 cubic feet per second.

The exportation of power by this company into the United States began in 1905, being less than 1,000 horsepower. It increased rapidly from year to year to a maximum of about 52,000 horsepower in 1917, since which time it has been held down by the Hydroelectric Commission to 50,000 horsepower or a little less.

In 1910 or 1911 the Ontario Power Co. entered into a contract with the Hydroelectric Power Commission of Ontario to supply it not less than 8,000 horsepower, and as much more as required up to 100,000 horsepower, at \$9.40 per horsepower per annum for power at 12,000 volts until 25,000 horsepower is taken, and for \$9 per horsepower per annum for all additional power. These prices are increased \$1 each for power supplied at 60,000 volts. The prices cover 24-hour continuous service, the power to be delivered to the commission's lines in Niagara Falls, Ontario. The agreement is for a term of 10 years with provision for three extensions of 10 years each.

The Niagara, Lockport & Ontario Power Co., formerly a subsidiary of the Ontario Power Co., made a contract with the Ontario Power Co., dated July 16, 1904, by which the latter agreed to supply the former at the international boundary line 60,000 horsepower, with the option that the amount might be increased to 180,000 horsepower. At the time of the sale of the Ontario Power Co., August 1, 1917, this contract was altered to cover a maximum amount of 50,000 horsepower, and the date of expiration was changed from 2010 to 1950.

The general location of this plant is shown on plate No. 13.

Toronto Power Co.—The power plant now generally spoken of as that of the Toronto Power Co. was constructed by the Electrical Development Co. of Ontario (Ltd.). It diverts approximately 12,400 cubic feet of water per second from Niagara River on the Canadian side above Horseshoe Falls.

The Electrical Development Co. of Ontario (Ltd.) owns the hydroelectric power plant, franchises, etc., all of which are leased to the Toronto Power Co., which agrees to pay as rental the annual interest and sinking fund on the bonds, and, if net earnings from the leased property permit, dividends on the preferred stock. The outstanding capital stock of the Electrical Development Co. is \$3,006,100 common, of which the Toronto Power Co. owns \$2,983,900; and \$2,990,900 preferred, of which the Toronto Power Co. owns \$2,990,600. The preferred stock is entitled to 6 per cent noncumulative dividends until January 1, 1910, and 6 per cent cumulative dividends thereafter. The outstanding bonds amount to \$9,669,500, of which the Toronto Power Co. owns \$5,014,000. The Electrical Development Co. owns or controls several subsidiary companies.

The Toronto Power Co. capital stock authorized is \$6,000,000 and issued is \$3,000,000. The Toronto Railway Co. owns \$2,000,000 of this direct, and the remaining \$1,000,000 through a subsidiary company. There is a "bonded debt," covering \$4,100,200 of 5 per cent bonds, guaranteed by the Toronto Railway Co., issued to cover the preferred stock of the Electrical Development Co. held by the Toronto Power Co., and which is mortgaged to cover this issue. There is also an issue of $4\frac{1}{2}$ per cent "debenture stock" amounting to \$1,218,400, guaranteed by the Toronto Railway Co., and secured by mortgage on \$2,000,000 of Electrical Development Co. bonds, and four-fifths or more of Electrical Development Co. common stock. In addition there is an issue of $4\frac{1}{2}$ per cent "consolidated guaranteed debenture stock" to the amount of \$15,140,500, guaranteed by the Toronto Railway Co., overlying the remaining \$3,014,000 of Electrical Development Co.'s bonds and a few other securities.

The general location of the power plant is shown on plate No. 13. The scheme of development involves a diverting dam or weir in the rapids, a power house parallel to and along the shore, a long, deep, narrow wheel pit running longitudinally under the power house, and a tailrace tunnel extending from the pit to a point beneath the Horseshoe Falls.

On January 29, 1903, the commissioners of Queen Victoria Niagara Falls Park granted a syndicate an irrevocable license to construct a hydroelectric plant in the park according to stipulated plans, and to develop thereby 125,000 horsepower. This grant was confirmed

by order in council the following day. The syndicate was consolidated into the Electrical Development Co. of Ontario (Ltd.) on February 18, 1903, by royal letters patent, and on March 21, 1903, the rights of the syndicate were assigned to the company. This assignment was confirmed by the Ontario Legislature.

The terms of the lease are identical with those of the lease to the Canadian Niagara Power Co., which have been stated previously. The date of the license is February 1, 1903.

The plans of the company, which were approved, called for 11 units of 12,500 nominal horsepower each, one unit being regarded as a spare. The quantity of water to be diverted was not specified, but was variously estimated in 1906 or earlier to be 10,800 cubic feet per second, and 11,200 cubic feet per second.

The intake and power house are on the Canadian bank of the river about 3,000 feet above the Canadian end of Horseshoe Falls, and nearly midway between the intakes of the Ontario Power Co. and the Canadian Niagara Power Co. The intake is somewhat similar to that of the Ontario Power Co., while the power house arrangement is, to an extent, like that of the Canadian Niagara Power Co.

A submerged weir or diverter similar to that of the Ontario Power Co.'s intake extends into the rapids, curving upstream and having its upper end open. The crest is at elevation 527, except at the inner end, which is dropped to elevation 524 to insure a good current across the curtain wall. The length of the weir is about 700 feet. At the shore end of the weir is a curtain wall parallel to the shore and the power house, about 480 feet long, pierced by 23 arches, each $14\frac{1}{2}$ feet wide and $20\frac{1}{2}$ feet high, with their crests 5 feet below mean stage. Inside this wall is a long, narrow fore bay with an ice run at its lower end. The landward side of this fore bay is a similar curtain wall, which also forms the outer wall of the power house. Beyond it is an inclosed inner fore bay with another ice run. The racks are placed in this fore bay. This arrangement solves the ice problem almost perfectly, and this plant has less trouble with ice than any of the others.

Behind the racks the water enters the 11 steel penstocks, each approximately 11 feet in diameter. The upper end of each penstock can be closed by a gate. The penstocks descend into the wheelpit, first at an angle of about 45° and then vertically. The pit is 416 feet long and 22 feet wide and is lined with brick. The finished bottom of the pit is about 145 feet below the water surface in the fore bay. The bottom of the pit does not form the tailrace as in the other plants of the "pit" type. Instead there are two tailrace tunnels, one 520 and the other 580 feet long, parallel to the pit, one on each side at the bottom.

There are 11 turbines in steel drums in the pit. Each has a single draft tube, and they discharge alternately left and right into the tailrace tunnels. These draft tubes are 9 feet in diameter and 70 or 80 feet long, with two right-angled elbows and one obtuse elbow. They discharge upward into the bottoms of the tunnels. The velocity through them is about 17 or 18 feet per second. The loss of head due to friction is greater than the "draft-tube effect," hence the tubes are under pressure throughout their length and add nothing to the effective head. The first four turbines have cylinder gates and a capacity of 13,000 horsepower each.

The generators are in the power house, a large ornamental building of Italian renaissance architecture. They are connected to the turbines by hollow steel shafts 115 feet long. Four of them are rated at 8,000 kilowatts and seven at 10,000 kilowatts each. They produce alternating current at 12,000 volts, 25 cycles. They are of the internal revolving field type, and each one has its own exciter mounted on top of the large machine. There are two small turbine-driven exciter units in a chamber at the northwest end of the pit, but they are seldom used.

The two tailrace tunnels unite a little ways from the pit to form the main tunnel. This is of horseshoe section, 23½ feet wide and 26 feet high. It is 1,935 feet long, and has a descending grade of 5½ feet per thousand. The last 300 feet of concrete lining at the portal is made in rings 6 feet long, calculated to break off as the fall recedes. The outfall or portal is behind the Horseshoe Falls, where its invert is at about elevation 366, some 12 feet or more above the usual water level in the pool below at this point.

The station is operated from a switchboard on a balcony in the power house. Cables laid in conduits carry the power to the transformer house, 1,500 feet southwest of the power house. Here much of the power is transformed to 60,000 volts for transmission to Toronto over the lines of the Toronto & Niagara Power Co. About one-sixth of the total power developed is imported into the United States over the lines of the Canadian Niagara Power Co.

The gross head of this installation from the intake in the Canadian rapids to the pool beneath the Horseshoe Falls is about 183 feet. From the best data available it appears that the plant is now diverting about 12,400 cubic feet per second, with which it generates about 125,000 horsepower. This shows 10.1 horsepower per cubic foot per second, and an over-all efficiency of 49 per cent.

The plant began producing power in 1906, and in 1907 power from it was first transmitted into the United States. In that year the exportation probably did not exceed 300 horsepower. It increased up to 8,000 or 9,000 horsepower in 1912, and then decreased, amounting to little or nothing in 1914 and 1915. In 1916 and 1917 it was nearly 20,000 horsepower, but decreased in the latter part of 1917 to about 15,000 horsepower. In 1914 the eleventh unit was installed. It was originally intended to be a spare, but the great demand for power, particularly during the war, led to its continuous use. It is understood that this continuous use was objected to by the Hydro-electric Commission of Ontario, except on condition that all the power produced because of it should be utilized in Canada and that certain differences between this company and the commission are now before the Ontario government for adjustment.

International Railway Co.—A small power plant on the Canadian shore between the crest of Horseshoe Falls and the power house of the Canadian Niagara Power Co. diverts from the Niagara River for power development a quantity of water estimated at 125 cubic feet per second.

The power rights for this plant were obtained on December 4, 1891, in an agreement between a syndicate of Canadian capitalists and the commissioners of Queen Victoria Niagara Falls Park in connection with a project to build and operate an electric railway between Queenston and Chippewa. This agreement was confirmed, and a

company, under title of the Niagara Falls Park & River Railway Co., was incorporated by act of the Legislature of Ontario. On May 3, 1894, a further agreement, subsequently confirmed, was made to cover the specific properties and construction rights involved.

The lease covers a period of 40 years from September 1, 1892, and under certain conditions may be extended 20 years. The annual rental of \$10,000 covers also the railway rights through the park. The amount of power to be generated or the quantity of water to be diverted are not specified, but under the charter of the company none of the power may be sold and none may be used except in operating and lighting the railway. In 1906 it was estimated that the ultimate consumption of water would be 1,500 cubic feet per second and that the consumption at that time was 600 cubic feet per second.

In 1900 the Buffalo Railway Co., of New York State, obtained Canadian incorporation, and in April, 1901, its Canadian rights were confirmed and extended. It purchased the properties, rights, etc., of the Niagara Falls Park & River Railway Co., paying \$733,000 for the equity and assuming the bonded indebtedness of \$600,000. It was reported in 1906 that at the time of the purchase the power plant represented a cash outlay of \$141,000, and that \$125,000 additional for equipment had been expended up to 1906.

In 1902 the name of the Buffalo Railway Co. was changed to International Railway Co. This company in October, 1903, applied to the park commissioners for approval of plans to transmit power from this plant to the American side to operate the extensive railway system in the State of New York. The request was not granted. The International Railway Co. operates the electric railways in Buffalo, Tonawanda, and Niagara Falls, N. Y., and elsewhere in Erie and Niagara Counties in New York State, as well as in Welland County, Ontario. It is in turn controlled by the United Gas & Electric Corporation, which controls a large number of public service corporations operating in 13 or more States.

The intake and power house of this plant are about 500 feet above the Canadian end of the Horseshoe Falls. The intake is simply a channel leading directly from the rapids. It is about 260 feet long, from 62 to 130 feet wide, and about 5½ feet deep. Its entrance is guarded by piers and coarse racks. The plant contains two small vertical turbines which operate under a head of about 64 feet. These discharge into a tunnel which spills its water into the gorge through a portal in the side of the cliff upstream from the Ontario power house at about elevation 420. One of the turbines is connected by bevel gears and belts to six small direct-current generators rated at 270 horsepower each. The other turbine is direct connected to a vertical direct-current generator rated at 2,000 horsepower. These machines are operated in parallel at 650 volts.

The average load of this plant is about 570 horsepower, of which about 175 horsepower is imported into the United States. The water consumed would seem, from the best data available, to be about 125 cubic feet per second. This corresponds to an over-all efficiency of 45 per cent and a power production of 4.6 horsepower per cubic foot per second. The tunnel spills its water far above the Maid-of-the-Mist Pool. The gross head measured to the surface of this pool is 165 feet, and the over-all efficiency on this basis is only 25 per cent.

The location of the power house is shown on Plate No. 13.

Water works of Niagara Falls, Ontario.—The city of Niagara Falls, Ontario, derives its supply of water for domestic use and fire protection from the intake of the International Railway Co.'s power house. From the north corner of this intake a conduit about 500 feet long leads the water under the park to a small pumping station near the crest of the Horseshoe Falls. Here part of the water is pumped into the city mains, the remainder furnishing the power to do the pumping. This latter portion is then discharged through a tunnel with an outfall near that of the International Railway Co. The elevation of the outfall is about 477 feet. The amount of water used is not known, but it certainly does not exceed 50 cubic feet per second. The water wheels are reported to be of 500 horsepower total capacity. The head used by the pumping machinery is about 25 feet.

As this diversion is made solely for sanitary and domestic purposes it is not to be included as part of the 36,000 cubic feet per second permitted to be diverted for power development on the Canadian side of the river, but rather as one of the diversions which are covered by the last sentence of Article V of the treaty.

The location of the pumping station is shown on plate No. 13.

New plant of Ontario Hydro-Electric Power Commission.—The Hydro-Electric Power Commission of Ontario is now building a new power development on the Canadian side. The following description of this project is based largely on an article in the Engineering News Record for October 31, 1918, and partly on other information.

The contemplated diversion is 10,000 cubic feet per second. The water is to be taken from the upper river at the mouth of the Welland River (Chippawa Creek) and flow up the Welland River nearly to the village of Montrose. This section of the river is to be dredged to a depth of 25 to 30 feet with a mean width of about 200 feet. The length of this section is about 3.6 miles. Leaving the river the water passes through a canal nearly 9 miles long to a fore bay at the edge of the Gorge a mile above Queenston. Location of the route is shown on Plate No. 6. The wetted section of this canal is 48 feet wide and 30 to 35 feet deep. It is mostly in rock with channeled sides and concrete lining. The cuts on this canal are very heavy. The maximum depth of rock cut is 85 feet and of earth more than 100, while the greatest total cut is 140 feet, of which about 75 is rock. The canal crosses the deep ravine west of the Whirlpool on an artificial fill.

It is worthy of note that the rock surface in this region dips to the west and this canal has a less proportion of rock excavation than one on the American side would have. A few miles farther west the New Welland Canal is being excavated almost entirely in earth. On the other hand an American canal would cut across the angle of the river and its length from intake to fore bay would be only about one-third that of the Canadian route.

The fore bay at the top of the cliff is approximately 300 by 1,000 feet. From it the water passes through six penstocks to the power house in the Gorge. Here there are to be six vertical units rated at 52,500 horsepower each, a total of 315,000 horsepower. The "net" head is 304 feet, and 300,000 horsepower is expected to be obtained from 10,000 cubic feet per second, or 30 horsepower per cubic foot per second. The estimated cost is only \$25,000,000, or \$83 per horse-

power. It is hinted that this is only the first of a series of such developments contemplated, with an ultimate diversion of 36,000 cubic feet per second.

In the light of the studies described in Section F of this report it must be said that these estimates seem altogether too optimistic. A rough computation of the power output and cost on a basis comparable to that of the projects discussed in Section F give a power output of 294,000 horsepower, or 29.4 horsepower per cubic foot per second, and a total cost of \$42,000,000, or \$143 per horsepower. This high cost as compared with the American projects is due almost entirely to the great length of canal required by this scheme.

While the canal is being built large enough for a diversion of 10,000 cubic feet per second, it is understood that the Hydroelectric Commission maintains that the present diversions on the Canadian side amount to 30,000 cubic feet per second and intends to install at present only sufficient machinery to utilize the 6,000 cubic feet per second thus estimated to remain under the treaty.

It appears that the present Canadian diversions really amount to about 33,325 cubic feet per second, and that when the Ontario Power Co.'s new units are put in service the amount will be more than 35,400. This would leave less than 600 cubic feet per second available for the new plant. Apparently, therefore, the commission must shut down part of the Ontario Power Co. plant when ready to start operating the new plant or else secure an extension of the treaty limit.

Niagara Falls Power Co.—The two power houses of the Niagara Falls plant of this company take water from a short canal on the American side above Goat Island and discharge it through a long tailrace tunnel into the Maid-of-the-Mist Pool. The 21 units of this plant have a rated capacity of 5,000 horsepower each. The permit from the Secretary of War authorizes the diversion of 10,000 cubic feet of water per second. About 750 cubic feet of this is leased to the International Paper Co., but is not now being used by them. The Niagara Falls plant is now using about 9,450 cubic feet per second, with which it produces about 100,000 horsepower. This is a production of 10.6 horsepower per cubic foot per second and represents on the gross head of 219 feet an overall efficiency of 43 per cent.

A detailed history and description of the works of this company will be found in Section F of this report.

Hydraulic Power Co.—This company has been consolidated with the Niagara Falls Power Co., and the plant is now known as the "hydraulic plant" of the Niagara Falls Power Co. The two power houses are in the Gorge on the American side about half a mile below the American Falls. They get their supply of water through a canal from Port Day about a mile above the Falls. The permit authorizes the diversion of 9,500 cubic feet per second. Of this the Pettebone-Cataract Paper Co. gets 271 cubic feet per second. Station 2 has 9 units, with a total rated capacity of 21,200 horsepower, and station 3 has 13 units, of a total rated capacity of 130,000 horsepower. This plant is now producing about 145,000 horsepower from 7,840 cubic feet per second. This is a production of 18.5 horsepower per cubic foot per second and corresponds to an overall efficiency of 75 per cent under the gross head of 219 feet. Three new units with a total capacity of more than 100,000 horsepower are now being installed.

A detailed history and description of this plant will be found in Section F of this report.

The Pettebone-Cataract Paper Co.—The Pettebone-Cataract Paper Co. diverts a small amount of water from the Hydraulic Power Co.'s canal for the manufacture of flour and paper. Its plant is described in Section F of this report. The company now uses about 271 cubic feet per second, from which it obtains perhaps 2,000 horsepower, or 7.4 horsepower per cubic foot per second. As the gross head of this plant is about 93 feet, the over-all efficiency is 70 per cent, but the tail water is rejected high up the bank, wasting a head of approximately 125 feet.

The International Paper Co. formerly diverted about 720 cubic feet per second from the canal of the Niagara Falls Power Co. for operating its large paper mill. This plant is briefly described in Section F of this report. The turbines have been removed and no water is now used by this company, but it is understood that they retain their old rights and intend to install new wheels.

Cataract Hotel plant.—There was formerly a small power plant in the basement of the Cataract Hotel, in Niagara Falls, N. Y. This took water from the American Rapids near the head of Goat Island by means of a wing dam and canal and discharged it through a tail-race tunnel into the same rapids near the Goat Island bridge. The hotel had certain water rights from the State of New York. When the State formed the present park the commissioners caused the greater part of the canal to be replaced by a brick-lined underground conduit 7 or 8 feet in diameter. The wing dam and upper part of the canal were retained, and still remain in the park.

The gross head of this plant is about 24 feet. Its one small turbine was operated intermittently until the fall of 1913 to run the hotel laundry. The amount of the diversion is unknown, but it was probably much less than 100 cubic feet per second. No permit for this diversion was ever granted by the Secretary of war.

In the fall of 1913 the present owner of the hotel, Mr. John F. MacDonald, removed the old machinery and purchased a modern hydroelectric unit, rated at 400 horsepower, which he proposed to install in its place. Owing to the refusal of the New York State authorities to allow the replacement of the old headgate of the conduit by new ones, this development has never been completed, and no water is now being diverted. The plant could probably use between 200 and 300 cubic feet per second. Mr. MacDonald is the promoter of the Empire Power Corporation, which desires to develop a large power plant on the site of the Cataract Hotel, as described in Section F of this report.

Comparison of plants.—The plants described above differ in gross head from 24 to 313 feet. Some make efficient use of the water diverted under the head which they have and others do not. Table No. 18 assembles the diversions, outputs, and efficiencies of these plants so that they may readily be compared. It should be noted that the horsepower per cubic foot per second is the figure which shows the relative success of the different plants in obtaining power from their diversions, while the over-all efficiency shows whether or not the installation is up to date. Where this latter figure is less than 80 per cent the output of the plant is not as great as it should be for the given gross head.

TABLE No. 18.—*Diversion data on Niagara Falls power plants.*

Plant.	Diversion.	Power output.	Gross head.	Horsepower per cubic feet per second.	Overall efficiency.
	<i>Cubic feet per second.</i>	<i>Horsepower.</i>	<i>Feet.</i>		<i>P. ct.</i>
Canadian Niagara Power Co.	9,800	100,000	173	10.4	53
Ontario Power Co.	11,200	103,000	215	14.6	60
Toronto Power Co.	12,400	125,000	183	10.1	49
International Ry. Co.	125	570	91	4.6	45
Hydro-Electric Power Commission ¹	10,000	294,000	313	29.4	83
Niagara Falls Power Co.	9,450	100,000	219	10.6	43
Hydraulic Power Co.	7,840	145,000	219	18.5	75
International Paper Co.			219		
Pettebone-Cataract Paper Co.	271	2,000	93	7.4	70
Cataract Hotel.			24		

¹ Now under construction.² The Hydraulic Power Co. has 3 types of machines with widely different overall efficiencies, as follows: Station 2, 57 per cent; direct current units in station 3, 77 per cent; alternating current units in station 3 81 per cent.³ Gross head taken at mouth of outfall.

This table shows that of the five existing large plants, that of the Hydraulic Power Co. is by far the most efficient, while the Ontario Power Co. is next, and the other three are about equally poor. Any future development ought to be planned for an over-all efficiency of more than 80 per cent, and ought to give over 20 horsepower per cubic foot per second if it discharges into the Maid-of-the-Mist Pool, or over 29 if it discharges into the Lower Rapids.

Total diversions.—The actual total diversion of water by the power plants at Niagara Falls is shown by the above table to be 17,561 cubic feet per second on the American side, and 33,325 cubic feet per second on the Canadian side, a grand total of 50,886 cubic feet per second. This produces 635,570 horsepower, or 12.5 horsepower per cubic foot per second.

7. ST. LAWRENCE RIVER NAVIGATION CANALS.

The amount of power developed upon the St. Lawrence River navigation canals is very small and the diversions for the purpose correspondingly small. Because of their slight importance no attempt has been made to determine them with accuracy. It should be noted, however, that the potential power in the river at each of these canals is large, and its development in the course of time seems almost certain.

For each of the canals considered in the following paragraphs a general description and a statement of its navigation features is to be found in Section A of this report. The canals are shown on plates Nos. 9 and 10, the power sites being indicated.

Galop Canal.—It is believed that an average diversion of 400 to 800 cubic feet of water per second is made at the Galop Canal for power development. The major portion of this quantity is conveyed down the old canal to a point southeast of the village of Cardinal, where it is used under a 6-foot head by the Edwardsburg Starch Works in its manufacturing process. This installation is reported to be 200 horsepower. At 50 per cent over-all efficiency this development would require a flow of 590 cubic feet per second. The plant is old and it might be even less efficient. On October 6, 1914, the flow to

this plant was carefully measured and found to be 480 cubic feet per second. The discharge from the mill enters the river through a gap in the old canal wall.

At Iroquois there are two small power plants with a 14-foot head. That belonging to M. F. Beach is listed at 40 horsepower, while the other, which is the water-works, pumping and electric-light plant of the town of Iroquois, is listed at 90 horsepower. The plant belonging to Mr. Beach contains modern vertical-shaft generating units whose efficiency might be 75 per cent. In this case the maximum quantity of water required is 34 cubic feet per second. The plant is operated only intermittently to run a gristmill and light part of the town of Iroquois. The town plant is old and its efficiency might be 50 per cent or less. At 50 per cent efficiency it would require a maximum of 115 cubic feet of water per second. It is not operated continuously. On October 6, 1914, the flow through the "Cardinal Cut" was accurately measured and found to be 260 cubic feet per second. This volume of flow covered the demand at that time for power development at these two plants, the waste over the weir at Lock 25, any possible lockage at Lock 25, and seepage and evaporation. These two plants at Iroquois are located northwest of Lock 25, the chamber of old Lock No. 25 forming part of the common tail-race.

Morrisburg Canal.—At the lower end of the Morrisburg Canal there are three small water-power plants owned by the city of Morrisburg. The head on each is approximately 11 feet. One has an 800 kilovolt-ampere generator, requiring 1,000 cubic feet of water per second for full load; another is a 300-horsepower city lighting plant requiring 300 cubic feet per second; and the third is the city water works, requiring 55 cubic feet per second for power. The total consumption of the three plants, namely, 1,355 cubic feet per second, is not continuous. On October 10, 1914, the flow in the canal was measured and found to be 950 cubic feet per second. This represented the entire use of water just at that time for both navigation and power purposes. It is believed that the average use for power development runs from 800 to 1,400 cubic feet per second.

In wintertime accumulations of ice downstream sometimes cause a backwater rise which occasionally reaches a height of 12 feet.

Cornwall Canal.—The flow in the Cornwall Canal has never been measured so far as is known. There is a development at Mille Roche, 5 miles below the head of the canal, and there are 5 developments at Cornwall, as shown in Table No. 19.

TABLE No. 19.—Water-power developments on Cornwall Canal.

Location.	Normal head.	Horse-power developed.	Water used.	Name of power user.
	<i>Feet.</i>		<i>Cubic feet per second.</i>	
Mille Roches.....	28	2,000	800	St. Lawrence Power Co.
Lock 18.....	7½	800	150	Toronto Paper Manufacturing Co.
Do.....	7½	50	10	Cornwall City Pumping Plant.
Lock 17.....	20	2,900	1,800	Canada Cotton Co.
Do.....	20	80	50	Cornwall Electric Light & Ry. Co.; Stormont Electric Light & Power Co.
Do.....	20	50	30	Hodge Flour Mill.
Total.....	.....	5,880	2,840	

A total diversion of nearly 3,000 cubic feet of water per second for power purposes is indicated, but the full amount is not used continuously. It is understood that in wintertime the plants at Cornwall are bothered considerably by backwater caused by accumulations of frazil ice in the comparatively quiet waters of Lake St. Francis. This backwater sometimes rises to a height of 15 to 30 feet above normal level.

Other canals.—Considerable power is developed along the Soulanges Canal and the Lachine Canal. The old Beauharnois Canal is used solely for power development. These canals, as already explained in Section A, are along that portion of the St. Lawrence which is entirely Canadian, and hence is considered to be outside the territory involved in this investigation. The largest single development is that of the Cedars Rapids Manufacturing & Power Co., on the north side of the river at Cedars Rapids. This plant utilizes a 30-foot head, developing approximately 130,000 horsepower, of which more than 60,000 horsepower is transmitted into the United States over a 110,000-volt line for consumption by the Aluminum Co. of America at Massena, N. Y. The designed contemplate an ultimate use of 56,000 cubic feet of water per second, generating 150,000 horsepower.

8. MASSENA CANAL.

The St. Lawrence River Power Co., which is controlled by the Aluminum Co. of America, diverts about 30,000 cubic feet of water per second from the St. Lawrence River at the head of the Long Sault Rapids in the State of New York, returning this water to the St. Lawrence at the mouth of Grasse River, 10½ miles downstream from the point of diversion.

The St. Lawrence River Power Co. was incorporated July 19, 1902, as successor to the St. Lawrence Power Co., which was sold under foreclosure. It has authorized an outstanding \$3,500,000 common stock and authorized \$3,500,000 preferred stock, \$3,000,000 of which is outstanding. All outstanding stock is owned by the St. Lawrence Securities Co., which was formed by the Aluminum Co. of America in 1906, and is owned by it. The St. Lawrence River Power Co. has no bonded debt.

The canal and other main works of this company are shown on Plate No. 10.

The head of the Massena Canal is in the South Sault Channel, about 1 mile below Talcotts Point, which is at the head of the South Sault Rapids. In this reach of the river the power company has dredged a channel 150 feet wide and 14 or more feet deep, leading toward the head of the canal.

The canal extends in a southeasterly direction from its entrance. 16,200 feet to the Grasse River at Massena, N. Y. It has a bottom width of 188 feet, depth of 25 feet, and side slopes of 1 on 1½. The effective wetted cross-section is about 5,500 square feet. It passes through two ridges, each over 2,000 feet long, requiring maximum cuts of 80 and 90 feet, respectively. The excavation was almost wholly in earth. The canal was designed to be navigable. Of the three bridges which cross it one has 60 feet of headroom and the other two have lift draw spans.

The power house stands at the end of the canal, its foundation forming a dam across the canal, and its face, on the tailrace side, extending along the north shore of Grasse River. The old and new power houses form one continuous structure. In the new power house there are five vertical shaft units. Each shaft carries two turbine runners, mounted one above the other in an open concrete stall. There is a separate draft tube for each runner, the two tubes uniting in a common tailrace under the river wall of the power house. Four of these units drive direct-current generators, and one drives an alternator, each generator being direct connected on the upper end of the shaft. Both the turbines and the generators are of Allis-Chalmers manufacture, and each unit is said to have a nominal rating of 6,000 horsepower. The old power house contains eight horizontal shaft units of 5,000 horsepower each. These units consist in each case of six separate turbine runners of 1,000 horsepower each on the same horizontal shaft in a concrete stall, and a single generator on the end of the shaft in the generator room. Four of the turbines are Dayton Globe Iron Works machines, two of which drive Bullock direct-current generators, while the other two drive Westinghouse direct-current generators. The other four turbines are I. P. Morris machines, two driving General Electric direct-current generators, and two driving Westinghouse alternating-current generators.

The tailrace of the plant is formed by the Grasse River, which runs nearly parallel to the St. Lawrence, and, in this locality, within $3\frac{1}{2}$ miles of it. It is 7 miles along Grasse River from the power house to the St. Lawrence. Originally, this reach of the Grasse River was 250 to 300 feet wide and very shallow. Dredging performed in 1914 to 1918 produced a channel 200 to 600 feet wide and 14 or more feet deep throughout the 7 miles, the current in which is less than $3\frac{1}{2}$ miles per hour.

The discharge into the upper end of the South Sault Rapids was normally about 50,000 cubic feet per second, or, roughly, one-fifth of the entire flow of the St. Lawrence. The fall from the head of the Massena Canal to the mouth of Grasse River was approximately 43 feet. Until recently when operating to capacity the power company lost about 7 feet of head in the Grasse River and $2\frac{1}{2}$ feet in the canal, leaving a head of $33\frac{1}{2}$ feet on the plant, under which about 80,000 horsepower was produced with a use of 30,000 cubic feet of water per second. In winter time there was a great deal of trouble with floating ice, anchor ice, and frazil, and the power house could be operated at only a fraction of its summer capacity, the head at the power house often being reduced to 25 feet, the flow of water to 5,000 cubic feet per second, and the power output to 10,000 horsepower.

In an endeavor to remedy ice difficulties, and as a temporary expedient to provide more power for the manufacture of munitions of war, the company constructed ice-diverting works of special design at Talcotts Point in the summer and autumn of 1918, and a submerged rock dam across the South Sault Channel just downstream from the canal entrance. As a result of these works and the mild winter of 1918-19 the difficulties with ice were greatly minimized, and the plant was able to maintain an output of 45,000 to 55,000 horsepower. Furthermore, because of the increased head of about 3 feet

at the head of the canal, the consequent increased carrying capacity of the canal, and the increased discharging capacity of Grasse River due to dredging, the head at the power house has been increased 8 or 9 feet. The fall in the canal has been reduced to approximately 1 foot and the fall in Grasse River to about $2\frac{1}{2}$ feet. An output of 60,000 horsepower is now produced with a consumption of only 17,000 cubic feet of water per second. Under these conditions the fall in Grasse River was about 2 feet and the head at the power house about 43 feet. Nearly all the power is used in the near-by work of the Aluminum Co. of America. A very small amount is used for lighting and pumping at Massena.

The St. Lawrence Power Co., which originated the development of this plant, was incorporated in New York State in 1896. Construction work was undertaken soon after, and had progressed to a point in 1902 where 35,000 horsepower was available. Owing to its relatively inaccessible location no market for the power was developed and the project became a financial failure. Foreclosure proceedings were undertaken on behalf of the bondholders, and on July 3, 1902, the property and franchises were sold to Mark T. Cox, one of the incorporators of the St. Lawrence River Power Co., for \$500,000. It was reported that up to that time the development had cost more than \$10,000,000, the funds being supplied by English capitalists.

9. LITTLE RIVER AT WADDINGTON, N. Y.

Ogden Island, formerly known as Crapseys Island, forms the southerly shore of the Rapide Plat. These rapids and the Morrisburg Canal following their northerly shore, have been described in Section A of this report. The channel between Ogden Island, which is United States territory, and the American main shore is known as Little River. It is approximately $3\frac{1}{2}$ miles long, 600 to 1,500 feet wide, and generally shallow, the midstream depth varying from 6 to 35 feet. On the mainland, a little below mid length of Little River, is situated the town of Waddington, N. Y., 18 miles downstream from Ogdensburg, N. Y.

At Waddington there is a dam 950 feet long across Little River which was originally built more than 100 years ago. It is reported to have been constructed of stone originally, but the present structure appears to be largely of wooden cribs filled with bowlders, a part of the length being dry rubble wall. It is very dilapidated and leaky. The head of water on the dam is approximately 10 feet.

At the downstream side of the dam, near midstream, is a small power house owned by the New York & Ontario Power Co. It contains a 39-inch Victor turbine, whose maximum discharge at full gate is about 110 cubic feet per second. It drives a generator which furnishes power for lighting the village of Waddington from sunset to 1 o'clock a. m. daily. Its power may also be used for pumping water for fire protection and street flushing.

A power canal 15 to 20 feet wide leads from the south end of the dam downstream along the bank of the river for about 950 feet. It serves four small plants. Beginning near the dam there is a small sawmill owned by the New York & Ontario Power Co. and operated by Dunn & Rutherford, of Waddington. It has an old-style, wooden scroll, central discharge wheel which is very wasteful of water, using

200 to 300 cubic feet per second when operating, but which is run only part of the year. Below the sawmill is a blacksmith shop in which small tools are driven by a wooden, central discharge wheel using not more than 50 cubic feet of water per second. Below the blacksmith shop is a plant for separating cream from milk. It uses a wheel similar to that at the blacksmith shop and requires not more than 50 cubic feet per second. The fourth plant is below the separator and is a planing mill which is not in use more than one month a year. It has a wooden scroll, central discharge wheel requiring not more than 100 cubic feet per second. To recapitulate, the approximate amount of water used in all water-power plants on Little River is given in Table No. 20.

TABLE NO. 20.—*Little River water power—approximate present use of water in cubic feet per second.*

Electric lighting and pumping station.....	110
Sawmill.....	300
Blacksmith shop.....	50
Separating plant.....	50
Planing mill.....	100
Total	610

This quantity is about the same as that used in 1899.

About 900 feet upstream from the dam and parallel with it, there is a dike built partly of wooden cribs and partly solid fill. Toward the island end there are two openings or gaps in the dike spanned by small wagon bridges, one opening being 42 feet wide and the other 30 feet wide. On June 15, 1914, the flow of water through these gaps was gauged by current meter. The flow through the north gap was 1,850 cubic feet per second, and that through the south gap 750 cubic feet per second. The drop in water level from upstream to downstream side of the dike was found by leveling to be 1.5 feet. The leakage through the dike was estimated roughly to be 600 cubic feet per second. Altogether the flow through Little River was thus 3,200 cubic feet per second, a quantity which was 1.1 per cent of the total discharge of the St. Lawrence River at that time.

The right to construct the dam was originally granted to David A. and Thomas L. Ogden by act of the New York State Legislature April 1, 1808 (chapter 121, Laws of New York, 1808). This act conferred on these men and their associates for a term of 75 years the right to construct a dam and lock at Waddington, and to use the water impounded by the dam for the generation of power for any commercial purpose. On April 17, 1826, an act was passed (chapter 280, Laws of New York, 1826), setting forth the following:

David A. Ogden, of the county of St. Lawrence, being proprietor of both sides of the branch of the River St. Lawrence, in the town of Madrid (Waddington), and across which river he has erected a dam and locks in pursuance of an act passed April 1, 1808, shall, and he is hereby declared to be vested with all the rights of the people of this State to the lands situated below the said dam, and which by reason thereof has been rendered susceptible to improvement and extending down the branch of the said river from the said dam to the navigable waters thereof, to have and to hold to the said David A. Ogden, his heirs and assigns forever.

These two acts therefore vested in David A. Ogden and his successors in perpetuity all riparian rights on both sides of Little River, ownership of the bed of the river below the dam, and the right to

utilize the natural flow of the stream for the development of hydraulic power for any purpose whatsoever. The natural flow of Little River is reported to have been 26,000 cubic feet per second.

The New York & Ontario Power Co. now holds all these rights and privileges. This company was incorporated in New York State April 18, 1906, to furnish light and power to municipalities and industries in northern New York. It has an authorized capital stock of \$2,000,000, of which \$225,000 is outstanding. Its bonded indebtedness is \$200,000, the authorized bond issue being \$457,000. This company proposes to build a new dam about 1,000 feet downstream from the old one, remove the old dam and dike, dredge the channel, and construct remedial works, consisting of a submerged rock weir across the Rapide Plat at the head of the Morrisburg Canal, and a diversion wall from the foot of Ogden Island to Canada Island. With a use of about 30,000 cubic feet of water per second this company expects to develop 30,000 horsepower. Application for a permit has been made to the Secretary of War, and the matter has been referred to the International Joint Commission. A hearing was held by the commission October 1, 1918.

About 1911 the New York & Ontario Power Co. made a contract with the Hydro-Electric Power Commission of Ontario for the delivery of 15,000 horsepower at a sliding scale of rates varying from \$13 per horsepower per annum for the first 2,000 horsepower down to \$10.50 for each horsepower per annum above 10,000. The Hydro. Commission constructed a transmission line for a distance along the north side of the St. Lawrence River, and a start was made on construction of the river crossing to Ogden Island, just above Morrisburg. The power company failed to build its plant, however, and to fulfill its part of the contract.

The location of this project is shown on plate No. 9.

10. LONG SAULT RAPIDS PROJECT.

The Long Sault Rapids of the St. Lawrence River and the South Sault Rapids are shown on Plate No. 10. In the South Sault Rapids from Delany Island to the foot of Long Sault Island there is a fall of 32 feet, and from this point to the foot of Barnhart Island the fall is about 12 feet, giving a total head of 44 feet. The entire fall from Richards Landing to mouth of Grasse River is 48 feet, and from the head of the Cornwall Canal to the mouth of Grasse River it is 45 feet.

The average elevation of Lake Ontario for the 59 years, 1860 to 1918, both inclusive, was 246.18 feet. Under present conditions at this stage of the lake the St. Lawrence River discharges 241,000 cubic feet of water per second. Normally about 48,000 cubic feet per second of this went down the South Sault Rapids. At Barnhart Island the division appears to be, roughly, 226,000 south of Barnhart Island, 12,000 between Barnhart and Sheek Islands, and 3,000 through the Cornwall Canal north of Sheek Island.

On May 23, 1907, the Long Sault Development Co. was incorporated in New York to develop the power of the Long Sault and South Sault Rapids (chapter 355, Laws of New York, 1907). This company was owned by the St. Lawrence Securities Co., which in

turn is owned by the Aluminum Co. of America. Its authorized capital stock was \$1,000,000. The plans of this company involved a development of the Long Sault Rapids which required a dam 3,800 feet long across these rapids between Barnhart and Long Sault Islands, a dam 1,450 feet long between Barnhart Island and the bank of the Cornwall Canal at Lock 20, excavation of a channel 1,000 feet wide between Barnhart and Sheek Islands, and excavation of a channel through the lower end of Barnhart Island to two power houses at the water's edge. The head at these power houses was to be about 40 feet. The plans also included a development of the South Sault Rapids by a dam and power house at the east end of Long Sault Island, where a head of 35 feet was to be obtained. At mean stage, and 80 per cent over-all efficiency, the indicated horsepower is 1,027,000. At a low-river stage the power production would fall to 600,000 horsepower.

The company proceeded to purchase the whole of Barnhart Island, the lower half of Long Sault Island, all of the American main shore from the Massena Canal down to a point opposite the foot of Barnhart Island, and much other land on the islands and main shores in the vicinity, including all the riparian rights deemed necessary. It also undertook extensive engineering investigations related to the project.

To obtain the necessary congressional authority, a bill was introduced into the House of Representatives in February, 1907. This was later withdrawn, and in December, 1909, another bill was introduced. This also was withdrawn. Bills were introduced also in January, 1911, and 1912, but failed of passage, and no Federal authority was ever granted for the project.

Meantime the authority of the Parliament of Canada was also sought, but without success, there being much opposition to any attempt to develop the power of these rapids before Canada had developed a market capable of absorbing half the power produced. The navigation interests of Canada were unalterably opposed to obstructing the rapids. Much stress was laid on the danger of destructive ice blockades and their attendant floods.

The matter was referred to the International Waterways Commission which held public hearings by the full commission October 24, 1907, and November 21, 1908, at Toronto, and February 26, 1909, at Buffalo; and by the Canadian section of the commission November 6, 1907, at Montreal, and February 8, 1910, at Toronto. The Canadian members, however, failed to report, so that no report by the commission as a whole was possible. The American section reported favorably to the proposition on March 11, 1910.

In May, 1911, the constitutionality of the State grant was challenged, and on December 30, 1912, the attorney general of the State of New York rendered his opinion that the act granting the charter was unconstitutional. An act to repeal the act of incorporation was passed May 8, 1913 (chapter 452, Laws of New York, 1913). This act appropriated \$36,320 with which to refund the company the money paid by it into the State treasury. On the same date another act was passed empowering the State board of claims to adjudicate upon any claims that might be presented by the Long Sault Development Co. (chapter 453, Laws of New York, 1913).

The company claimed it had expended one and three-quarter million dollars or more in this enterprise, and argued that it should be reimbursed by the State.

In 1913 the court of appeals upheld the State's contentions. No reimbursement for development expenditures was allowed. In December, 1916, the United States Supreme Court handed down a decision declaring the charter of the Long Sault Development Co. unconstitutional and otherwise upholding the contentions of the State of New York.

11. ERIE & ONTARIO SANITARY CANAL.

The project of the Erie & Ontario Sanitary Canal Co. involves a diversion of 26,000 cubic feet of water per second from Lake Erie, just south of Buffalo, with which it is proposed to develop 800,000 horsepower. The project as a whole and its navigation features in particular have been described in Section A of this report, and its sanitary features in Section B. In Section F will be found a treatment of the power features in considerable detail.

W. S. RICHMOND.

APPENDIX B.

FIELD AND OFFICE OPERATIONS.

[Section D of Mr. Richmond's Report.]

At the beginning of this investigation operations were confined to office studies, conferences, and correspondence until the middle of September, when authorities had been secured and plans perfected for undertaking the field work which was essential to a comprehensive consideration of that portion of the investigation pertaining to Niagara Falls and the Niagara River. Following the assembling of field force and equipment and the securing of civil and military permits to enter private property and the carefully guarded grounds and plants along both sides of the Niagara River actual field work was commenced September 20, 1917.

Great difficulties were met with in securing proper assistance, due to war conditions. Eventually most of the technical personnel was drawn from the staff of the United States Lake Survey. In all 18 men were employed upon the field work, although the greatest number engaged at any one time was 15.

The extreme and long continued cold weather for which the winter of 1917-18 was noted was a further handicap to the rapid prosecution of the work. Temperatures below zero prevailed for days at a time, causing great hardship to the working force and delaying much of the work, particularly the rock sounding. This job was completed on February 8, 1918, and this day marked the completion of the field work except for minor items of reconnaissance.

Survey of Horseshoe Rapids.—The most difficult portion of the field work was the survey of the rapids of the Niagara River just above the Horseshoe Falls. The purpose of this survey was to provide data on the depth of water, its direction, and velocity of flow throughout a reach of rapids extending about one-half mile upstream from the Horseshoe Falls; also to obtain actual elevations above standard datum of the water surface at various points. This data was essential, first, to an intelligent study of the preservation of the Horseshoe Falls from destructive erosion and the matter of increasing its beauty by a better distribution of water along its crest; second, in estimating the total quantity of water which may safely be diverted from the Niagara River above the Falls.

The area to be surveyed lay between the crest of the Falls and the First Cascade. Its greatest length was 4,000 feet, and its greatest width 3,000 feet. Within this area the depth varies greatly, with a maximum of more than 10 feet. The velocity of the current ranges from 4 to more than 23 feet per second, and there are many cascades, standing waves, and areas of broken water. It is not safe for a boat to approach closer than within 1 mile of the upstream limit of the survey.

To measure depths and current velocities under these very adverse conditions was an undertaking of no small difficulty. The method finally adopted was a development of that used by the United States Lake Survey in 1906 and 1907 for somewhat similar work under much more favorable conditions. Briefly, it consisted of sending rod floats of known submerged lengths through the rapids and locating their positions at frequent intervals by intersections from two or more transits on shore. Plotting these locations gives the current directions. When floats do not touch the bottom the time elapsing between locations gives a measure of the velocity. When floats do drag on the bottom the observer estimates the angle of inclination, and from that the depth of water can be computed.

During the month of October, 1917, a number of experimental floats were built and tried. The first were broken in pieces on passing over the cascade, but a satisfactory design was soon worked out. For each float two short pieces of cedar fence post were fastened near the top of a 16-foot spruce 2 by 4. Above these a light frame of 1 by 2 inch pieces carried a flag and target of red and black cloth. At the lower end of the 2 by 4, sufficient ballast, in the form of cast-iron sash weights, was attached so that the whole floated in a vertical position with the bottom just 14 feet below the water surface, and the cedar blocks protruding just 1 inch out of water. This was called a "14-foot float." Floats were built on this principle in submerged lengths of 1, 2, 4, 6, 8, 10, 12, and 14 feet, except that in the smaller sizes 2 by 2 sticks were used instead of 2 by 4s. The 1 foot and 2 foot float did not give very satisfactory service. Floats of the 4, 6, 10, 12, and 14 foot lengths are illustrated in photograph No. 62.

The work of running and locating these floats was done in the month of November, 1917. The entire field force was used, being divided into six parties of two or three men each. Four of these were transit parties, consisting of an instrument man, a recorder, and, in one party, a signal man. The stations occupied by the transit parties are shown on plate No. 19, marked J, W, D, and H. Four transit parties were used to increase the number of successful locations and check their accuracy and also to obtain more estimates of angles of float inclination. Often a float would be invisible from one or more stations. When a float was passing through the rapids the signalman dropped a large flag at regular intervals, which fact was immediately called out by the four recorders to their respective transit men as the signal for simultaneous pointings upon the float. The transitmen thereupon read intersection angles, and, if the float was dragging on the bottom, estimated the angle the float made with the vertical. These observations were made at intervals of from 8 to 25 seconds, which required very quick work by both observer and recorder. Some intermediate observations of float striking or dragging were made and recorded. This frequency of reading was necessary because some floats made the whole trip from below the cascade to the crest of the falls in about 60 seconds.

The fifth party launched the floats from a small motor boat at points below Navy Island. The last party, which was furnished with an automobile, inspected and supervised the work, transported men, instruments, and materials to the various stations, and carried messages from one party to another.

This work was considerably delayed by rain, snow, and fog, but was completed during the month of November. The following figures give some idea of the magnitude of the work: Altogether 217 floats were used. These contained nearly 2,000 board feet of lumber and nearly $1\frac{1}{2}$ tons of sash weights. The launch ran more than 200 miles and the automobile about 300 miles.

Photographs Nos. 63 and 64 each show the automobile party and one transit party.

In the office reduction of this work the float locations were carefully plotted on a map of the rapids on a scale of 1=5,000. Lines connecting the successive locations of the same float gave the direction of the current at various points. These directions are shown on plate No. 19. The recorders' notes showed whether or not the floats were dragging on the bottom. In the case of those which were not dragging the distance between successive positions of a float were divided by the elapsed time, giving the current velocity in feet per second. These are plotted on plate No. 20. From floats that dragged on the bottom the depth of water at each location and intermediate point, was computed from the known submerged length of the float and the angle of inclination estimated by the transitman. The depths are shown on plate No. 21.

At times when floats were not being run, the transitmen read intersections and vertical angles to projecting rocks and other points on the water surface of the rapids which could be identified by two or more parties. From these the elevation of the water surface at these points was computed and plotted, and a rather rough contour map of the water surface was constructed on tracing paper. Superimposing this upon the sheet of depths the elevation of the river bottom was computed from each depth, and plotted on another sheet. A contour map of the river bottom was thus constructed, showing 5-foot contours. This is shown on plate No. 22.

This survey of the rapids, and the results obtained constitute a very satisfactory solution of the difficult problem of determining the hydrographic and hydraulic conditions above the falls. It is unfortunate that there were certain areas through which no floats could be made to pass. Nevertheless, the survey resulted in a very great increase in the knowledge of Niagara conditions.

Survey of crest line of Horseshoe Falls.—The survey of the crest line of the Horseshoe Falls was prosecuted at odd moments during December, 1917, and January, 1918, whenever an instrument and observer were available. The work consisted simply of intersecting various points on the crest from stations on shore. An effort was made to have the resulting line represent the edge of the rock cliff and not the curving surface of the falling water. This survey is well tied into the geodetic surveys of the International Waterway Commission and the United States Lake Survey, and through these to the previous crest line surveys of the lake survey and others. It is plotted on a scale of 1:2000 together with the results of earlier surveys on plate No. 18. The results of this work are discussed in Appendix C of this report. Table No. 21 contains descriptions of the various geodetic points in the vicinity of the Falls with their geodetic coordinates reduced to a common datum.

TABLE NO. 21.—*Triangulation stations used in survey of crest line and rapids.*

[Positions are referred to U. S. Standard datum.]

△ *M*.—This station, established by the New York State survey in 1890, is at the head of the stairs and path down to Terrapin Rock at the west end of Goat Island, being the center of a cross on the top of an 8-inch stone post buried 10 inches below the surface and surrounded by a piece of tiling which reaches above the surface of the ground.

Latitude $43^{\circ} 04' 50.03''$; longitude $79^{\circ} 04' 24.57''$.

△ *Terrapin*.—This station was established in 1886 by R. S. Woodward for the United States Geological Survey and is probably very close to the point of the same name used by the United States Lake Survey in 1875. It is a cross on a brass bolt expanded into a drill hole in the top of Terrapin Rock on the Goat Island end of the Horseshoe Falls. The name "Terrapin" is cut in rude letters on the rock around the bolt.

Latitude $43^{\circ} 04' 48.90''$; longitude $79^{\circ} 04' 28.06''$.

△ *Nail*.—This station was established in 1917 on the west side of Goat Island near the top of the bank and about halfway between △ *M* and △ *T. P.* No. 6. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 47.68''$; longitude $79^{\circ} 04' 23.59''$.

Boundary monument No. 21.—This station was established by the International Waterways Commission about 1912. It is one of the commission's standard monuments and is on the top of the bank on the southwest side of Goat Island about 560 feet southeast of the top of the path leading to Terrapin Rock.

Latitude $43^{\circ} 04' 45.40''$; longitude $79^{\circ} 04' 20.39''$.

NOTE.—The International Waterways Commission's triangulation gives the location of boundary monument No. 21 as—

Latitude $43^{\circ} 04' 45.36''$; longitude $79^{\circ} 04' 20.38''$.

△ *T. P. No. 6*.—This station was established in 1842 by James Hall, State geologist of New York. It is on the southwest side of Goat Island, about 470 feet southeast of the top of the path leading to Terrapin Rock, being a cross cut in the top of a stone post, 8 inches square, standing in the path and projecting 9 inches above the surface. The top of the stone is badly battered, but shows a rude "6" cut on one side.

Latitude $43^{\circ} 04' 45.68''$; longitude $79^{\circ} 04' 21.65''$.

□ *D*.—This station was established in 1917. It is at the top of the bank on the southwest side of Goat Island, about 30 feet west of △ *T. P.* No. 6. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 45.68''$; longitude $79^{\circ} 04' 22.08''$.

□ *H*.—This station was established in 1917. It is at the foot of the bank, near a timber sea wall on the south side of Goat Island, about 650 feet east of △ *T. P.* No. 6. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 43.72''$; longitude $79^{\circ} 04' 13.31''$.

□ *Walk*.—This station was established in 1917. It is on the Canadian side at the top of the cliff above the outfall of the Canadian Niagara Power Co.'s tunnel. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 48.97''$; longitude $79^{\circ} 04' 42.66''$.

Boundary monument No. 20.—This station was established by the International Waterways Commission about 1912. It is one of the commission's standard monuments and is on the Canadian side, about 130 feet southwest of the Canadian end of the Horseshoe Falls.

Latitude $43^{\circ} 04' 44.19''$; longitude $79^{\circ} 04' 42.83''$.

NOTE.—The International Waterways Commission's triangulation gives the position of boundary monument No. 20 as—

Latitude $43^{\circ} 04' 44.15''$; longitude $79^{\circ} 04' 42.80''$.

□ *1*.—This station was established in 1917. It is near the top of the bank on the Canadian side, about 100 feet southwest of boundary monument No. 20. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 43.36''$; longitude $79^{\circ} 04' 43.57''$.

□ *2*.—This station was established in 1917. It is near the top of the bank on the Canadian side, about 200 feet southwest of boundary monument No. 20. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 42.54''$; longitude $79^{\circ} 04' 44.32''$.

□ *S.*—This station was established in 1917. It is near the top of the bank on the Canadian side about 300 feet southwest of boundary monument No. 20. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 41.72''$; longitude $79^{\circ} 04' 45.08''$.

△ *Canal.*—This station was established in 1906. It is on the Canadian side just above the intake canal of the International Railway Co.'s power house, being a cross cut on a quarter-inch bolt in the top of a rough stone 12 by 18 by 18 inches, 3 inches below the surface of the ground. Stone is marked "U. S. △ L. S." It is 22.8 feet west of the southeast corner of concrete wall which runs south along the shore from the canal, 33.8 feet southwest from the northwest corner of same wall and 156 feet southeast from the south abutment of the railway bridge.

Latitude $43^{\circ} 04' 38.89''$; longitude $79^{\circ} 04' 45.26''$.

□ *W.*—This station was established in 1917. It is on top of the bank on the Canadian side, near its edge, about 325 feet south of the intake canal of the International Railway Co.'s power house. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 36.26''$; longitude $79^{\circ} 04' 44.48''$.

□ *J.*—This station was established in 1917. It is on top of the bank on the Canadian side, near its edge, about 130 feet northwest of the Toronto Power Co.'s power house. It is marked by no permanent monument.

Latitude $43^{\circ} 04' 21.82''$; longitude $79^{\circ} 04' 29.94''$.

△ *Lorretto.*—This station is the center of the cross on the Lorretto Convent on the high bank west of the Michigan Central Railroad Co.'s tracks, south of the Falls View Station. This point was located by R. S. Woodward in 1886. In 1890 the New York State survey placed a brass screw in the tin deck of the cupola directly under the center of the cross and occupied that station.

Latitude $43^{\circ} 04' 32.85''$; longitude $79^{\circ} 04' 57.11''$.

Float measurements in the Gorge.—For the study of the effect of building a dam at the foot of Fosters Flats further knowledge of hydraulic conditions in the rapids below and above the Whirlpool was necessary. There are published records of soundings taken at most of the points where sounding operations are possible without great expenditure of time and money. It was not thought that the expense of further soundings would be justified by the value of the results. Instead it was decided to obtain a few velocity measurements. As the total flow through the rapids at any time is known, and also the width at any point, the cross sectional area and mean depth could be determined roughly from the velocities shown by a few floats.

Six bases, of various lengths ranging from 100 to 300 feet, were laid out in the rapids. They were located as follows: No. 1 was just upstream from the Whirlpool; No. 2 was just upstream from the Eddy Basin, No. 3 was 2,000 feet downstream from the Michigan Central Railroad bridge, No. 4 was 600 feet downstream from the same bridge, No. 5 was abreast of Thompsons Point, and No. 6 was at the head of Fosters Flats.

The floats used were rod floats that had been prepared for use in the survey of the Horseshoe Rapids but had not been needed there. Most of them were 14 feet in length, although lengths of 4, 6, 7, 8, and 10 feet were also used. The floats were lowered into the river from the Grand Trunk Railway bridge or thrown from the American shore at the exit of the Whirlpool. The time of passing the bases as observed on stop watches and the distance of the floats from the American shore was estimated. In all 48 floats were run. The velocities observed varied from 5.5 to 38 feet per second.

Plats were made of the velocities observed at each section, rough transverse velocity curves drawn, and an estimate of the mean

velocity of the whole stream made. Dividing the discharge of the river by this velocity gave the cross sectional area, and this divided by the width gave the mean depth. In addition four sounded profiles of the Gorge made by Canadian surveys were available and two profiles from the work of the Lake Survey.

The Gorge from the American Falls to the foot of Fosters Flats was then divided into five sections, and, from a study of all the available data, mean values for the width and hydraulic mean depth were adopted. Values of "n," the coefficient of roughness, were then adopted for each section such that by using Manning's formula,

$$V = \frac{1.486}{n} R^{1/6} \sqrt{RS},$$

the computed slope for each section was the same as the slope shown on the Lake Survey mean profile of the Lower Niagara River. The values of "n" used varied from 0.050 in the smoothest section to 0.057 and 0.059 in the swiftest rapids.

Backwater computations were then made by successive approximations in the usual manner to show how much the water in different parts of the Gorge would be raised by a dam at the foot of Fosters Flats.

Table No. 22 shows the amount of rise at three different points that would be caused by dams of various heights at the foot of Fosters Flats.

TABLE NO. 22.—Amount of backwater rise at various points in the Gorge by dam at foot of Fosters Flats, where present mean stage elevation is 272.

Elevation of water at crest of dam.	Backwater rise at—			
	Foot of Foster Flats.	Whirl-pool gauge.	Suspension Bridge gauge.	Maid of the Mist landing.
325.....	53	34.71	1.59	1.59
335.....	63	44.15	5.47	5.44
340.....	68	48.91	8.17	8.10
344.....	72	52.80	10.78	10.69

Photographs.—An important part of the field work was the taking of a series of photographs showing the appearance of various parts of the river at different stages. On October 30, 1917, a full set of photographs was obtained at an extremely high stage of the river. On November 7 and 8 a set was obtained at a little above mean stage. Attempts to get pictures at an extreme low stage failed, as such stages only occurred during heavy northeast gales accompanied by rain or snow, during which time it was quite impossible to get satisfactory photographs. A third set was obtained on December 3, 7, and 18, when the stage was a little below the average. In all 54 photographs were taken. These pictures are presented and discussed in Appendix C of the report.

Other photographs were taken showing the methods and equipment used in the field work.

Gauges.—The first field work accomplished was the installation of automatic water gauges. Reconnaissance for this work was begun on September 20, 1917, and the last gauge was installed on October

27, 1917. Much other work was done during this period. The principal use of these gauges was to determine the discharge of the river at the times of taking photographs or running floats. It was also desired to obtain more accurate data on the slope of the lower river between the Maid of the Mist Pool and Lewiston to disclose any possible changes of importance in regimen of the river due to increased diversions of water for power development, or erosion of the Horseshoe Falls, and to strengthen and expand the data on which predictions of future effects of erosion and diversions had very largely to be based.

Eight automatic gauges were installed. They were Lake Survey gauges of the "Wilson type." The main vertical scale on each was 3 inches to the 1 foot, and the time scale was 2 inches to 1 hour. The supplementary vertical scale was one-half inch to the foot on the Chippawa, Terrapin Point, Prospect Point, and Lewiston gauges and one-fourth inch to the foot on the others. Each instrument provided a continuous graphic record of the water surface elevation at the gauge site.

The Chippawa gauge was located on the face of a dock on the north side of the Welland River (Chippawa Creek), about 200 feet east of the highway bridge and about 400 feet west of the position occupied by the United States Lake Survey's Chippawa gauge of former years. The gauge was installed October 11, 1917.

Photograph No. 65 shows this gauge in position.

The International Railway intake gauge was located on the face of the park wall on the Canadian side of the Niagara River just downstream from the intake of the International Railway Co.'s power house. This is the position formerly occupied by the United States Lake Survey's gauge of the same name. The gauge was installed October 9, 1917. It is shown in photograph No. 66.

The Terrapin Point gauge was located at Terrapin Point, near the eastern end of the Horseshoe Falls, in the identical position used for the United States Lake Survey's Terrapin Point gauge. It was installed October 3, 1917, and maintained till December 6.

The Prospect Point gauge was at Prospect Point, at the American end of the American Falls, a few feet from the brink of the Falls. It was placed as closely as possible in the position of the gauge formerly maintained at this point by the United States Lake Survey. The gauge was installed October 27, 1917, and maintained until December 10. A picture of this gauge is given in photograph No. 68.

The Suspension Bridge gauge was in the Gorge on the American shore about 160 feet upstream from the Michigan Central bridge in the location occupied by the United States Lake Survey gauge of the same name in former years. This gauge was installed September 26, 1917. It is illustrated in photograph No. 67.

The Whirlpool gauge was located on the Canadian side of the Whirlpool about 300 feet southeast of the mouth of a small creek entering the south side of the pool. This is the position occupied by the Lake Survey's Whirlpool gauge. The gauge was installed October 15, 1917.

The Lower Gorge gauge was located in the Gorge on the American side above Lewiston, opposite and just upstream from Smeatons

Ravine. This gauge was installed September 29, 1917, in the vicinity of various proposed power-house sites to obtain new data on water elevations and fluctuations at this point, including backwater effects of Lake Ontario. It is a notable fact that this gauge was at the foot of an eddy along the American shore and showed higher elevations of the water surface than existed several hundred feet farther upstream.

A picture of this gauge is shown in photograph No. 129.

The Lewiston gauge was on the downstream end of Pitz Dock at Lewiston, N. Y., about 4 feet east of the northwest corner of the dock. The Lake Survey's Lewiston gauge was formerly located at the other end of the dock, about 200 feet upstream. This gauge was installed October 1, 1917.

The location of all of these gauges is indicated on the general topographic map constituting plates Nos. 13 and 14 of this report.

The very unusual high stage of December 9, 1917, the highest in 40 years, put several of the gauges temporarily out of commission. In order to gain as much data as possible regarding this maximum stage, a level party was employed to determine the elevations of the high-water marks which were left at some of the gauge sites. These values are given at the foot of Table No. 23. The maximum registered by the "engineer's gauge" at Buffalo on this date was 579. By the accepted discharge formula a continuing elevation of 579 at Buffalo would correspond to a flow of 366,000 cubic feet per second through the Niagara River.

It may be of interest to note the weather conditions which produced this unusual rise. The United States Weather Bureau reports that a heavy gale from the northeast with heavy snow prevailed on the 8th of December. The barometer went down to the very low value of 29.05. During the night the wind shifted to the west and increased in violence, attaining a maximum velocity of 78 miles per hour. The gale continued strong until nearly midnight. The fall of snow during these two days amounted to nearly 2 feet. The minimum temperature was 6° above zero at 9 a. m. on the 9th. The gauges showed an unusually low stage on the 8th and extremely high on the 9th. Under the existing weather conditions it was quite impossible to obtain photographs of the high-water conditions or take any other advantage of the unusual state of affairs.

The record obtained from these gauges is fragmentary and incomplete because of the unsatisfactory condition of the gauge instruments and because of various vicissitudes which the gauges experienced, partly due to neglect necessitated by the pressure of other work. It was ample, however, for the purpose of the investigation.

The gauge records were worked up in the usual manner and elevations scaled from them to the nearest hundredth of a foot for every hour. The daily means are tabulated in table No. 23. Values marked with an asterisk (*) are the means of days where four or more hourly scalings are missing. The elevations given are above mean sea level according to the level adjustment of 1903. For purposes of comparison the scalings of the United States Lake Survey's Buffalo gauge have been included in the table.



Photograph No. 83 (2.12 p. m., Oct. 30, 1917).- AMERICAN FALLS FROM CANADIAN SIDE.
River discharge 275,000 cubic feet per second. Approximate flow over Falls 225,000 cubic feet per second

The various gauges on the Niagara River serve as measuring devices for measuring the flow of the river or of one channel of the river at any particular point. If artificial or natural changes in the regimen of the river did not occur, the relation between different gauges would be constant. Any change in these relations indicates a change in regimen, the most important being due to increased diversion by the power companies or to recession of the Falls. An unpublished report of the United States Lake Survey, dated 1912, gives an analysis of the effect of diversions upon the various gauges above the Falls as shown by the changes in their relations to the Suspension Bridge gauge. The observations of 1917 were used in combination with earlier Lake Survey records in computations and studies the results of which are as follows:

Buffalo gauge.—The computed lowering due to increased diversion since 1912 was 0.03 foot. The observed lowering was 0.02, an excellent check.

Chippawa gauge.—Computed lowering since 1912, 0.15 foot, observed lowering 0.18, an excellent check.

International Railway intake gauge.—Computed lowering since 1912, 0.64, observed lowering 1.03. This leaves an unexplained lowering of 0.39. Similar excess of lowering has been observed in the past, and very reasonably has been referred to as the effect of the recession of the Horseshoe Falls.

Prospect Point gauge.—If it be assumed that the division of water between the two sides of Goat Island has remained constant the computed lowering due to increased diversion since 1906 is 0.07 foot. It is probable that the increased diversions of the American companies have decreased the percentage of flow through the American channel. In this case the lowering would be greater than 0.07 foot. The observed lowering was 0.12 foot.

Terrapin Point gauge.—The gauge relations of this gauge have never been satisfactory. Observations in 1906 and 1912 gave widely different relations. By the 1906 relation the computed lowering is 0.29, while only 0.22 was observed. If the 1912 equations are used the computed lowering is 0.05, and the 1917 observations indicate a rise of 0.02. In either case there is a discrepancy of 0.07 foot. This gauge is located in a shallow stream of water at the Goat Island end of the Horseshoe Falls, and does not appear to reflect accurately the conditions of the river as a whole. The use of the gauge in studies of the regimen of the Niagara River is to be avoided when possible.

The Suspension Bridge and Whirlpool gauges each record the flow of the whole river through channels in which no artificial changes have been made for many years. They were maintained in 1906, 1907, 1908, 1909, 1910, and 1917. The five later years agree in showing a relation by which a change of 1 foot in the Suspension Bridge gauge is accompanied by a similar change of 1.17 feet at the Whirlpool. The absolute elevations at the Whirlpool corresponding to given stages at Suspension Bridge vary by small amounts, always less than 0.20 foot, from year to year. These variations follow no systematic course, and probably represent small local changes at the gauge sites. The records for 1906 were few, covering only a small range, and they appear to be somewhat discordant. The relation for 1917 coincides almost exactly with that for 1907, and very closely

with that for 1908. The 1909 and 1910 relations show elevations at the Whirlpool lower by more than one-tenth of a foot.

The Lower Gorge gauge.—Occupied an entirely new site. In relating it to the other gauges it was necessary to take into account the fact that water surface elevations at the site are dependent on the elevation of Lake Ontario to some extent, as well as upon the elevation of Lake Erie. For this reason it was necessary to derive an equation with three variables. The gauges used were Whirlpool, Lower Gorge, and Lewiston. There were 17 days on which each of these three gauges simultaneously gave a good, reliable record, with no missing hourly scalings. The derivation of the relation from these values involved considerable analytical difficulties, due to the small number of observations and the small range of stage that occurred at the Lewiston gauge. The relation finally adopted was—

$$\text{Lower Gorge} = 247 + 0.000043 (\text{Whirlpool} - 249.56)^2 + 0.77 (\text{Lewiston} - 247).$$

At mean stage Whirlpool is at elevation 292.51 and Lewiston is 246.73. By the relation given above Lower Gorge is 250.20. At standard low water Whirlpool is 286.24 and Lewiston is 243.38. This gives 246.34 for the standard low-water value at Lower Gorge.

This relation is believed to be the best obtainable from the data available. It could doubtless be improved by maintaining these three gauges carefully for a full season or longer.

Profile of lower river.—In 1912 the United States Lake Survey compiled standard profiles of the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers. The upper part of the Niagara profile was well determined by numerous gauges, but in the lower river, and especially in the rapids of the lower river, the data used was scanty and rather poor. In the studies of power-house locations along the rapids below Devils Hole it was very desirable to have more accurate data on water-surface elevations of this part of the river. It was intended to make observations at high, low, and medium stages, but very low water occurred at times when no men were available for this work, and the low-water profile observed differs but slightly from the one made at mean stage.

For the purpose of obtaining these profiles a large number of gauge points were established along the river from the Suspension Bridge gauge to Lewiston, and the elevation of these points were carefully determined.

On December 6 and 7, 1917, the vertical distance from the gauge point to the water surface was read at 40 of these points. During the reading the mean water-surface elevation was 292.07 at the Whirlpool gauge, 250.38 at the Lower Gorge gauge, and 247.10 at the Lewiston gauge. The fluctuations that occurred during the readings were, respectively, 1.14, 0.56, and 0.15 feet. These readings and the automatic gauge records gave the data for the mean stage profile.

On December 8 another set was read, but owing to bad weather and limited time, and the fact that the water was too low for measurement at some points, only 14 readings were made. The mean gauge readings at the Whirlpool, Lower Gorge, and Lewiston gauges

were 291.11, 250.33, and 247.26, respectively, while the fluctuations were 0.47, 0.31, and 0.22. These readings and records furnished the data for the low-water profile. As noted above, much lower values would have been desirable.

On December 9 the highest stage of the season occurred, but weather conditions were such that gauge readings could not be obtained. On the following day the stage was still high, and, despite the difficult conditions, readings on five of the most important points were obtained. Many of the gauge points were found to be submerged and no readings could be made on them. The elevations of the three automatic gauges were, respectively, 298.23, 254.48, and 247.75, while the fluctuations of these gauges during the period of the readings were 0.90, 1.17, and 0.24. Both the Whirlpool and Lewiston gauges had been stopped by the high stage of the preceding day, and elevations at these two points were supplied by gauge relations from the record of the Hydraulic Power Co.'s gauges at station 2 and Lewiston, respectively.

It was next necessary to reduce all observations on each profile to values corresponding to the mean stage prevailing during the measurement of the profile. In doing this all available evidence was taken into account. The observed ratios of fluctuations were given the most weight, but the general laws of hydraulics and the nature of the river channel were also considered. The three profiles were then carefully plotted, as shown on plate No. 15.

The values were then reduced to the official mean stage and standard low water of the Whirlpool and Lewiston gauges, as shown on the Lake Survey profile of 1912. The Lake Survey profile was then replotted on a different scale, the new profile between the Suspension Bridge gauge and Lewiston being incorporated. This profile is shown on plate No. 11. It was used as the basis of all computations of slopes, fall, etc., in the present investigation. The official mean stage profile differs but very little from the observed mean stage profile of plate No. 15, and may be considered well determined. In places along the American shore there are eddies and current retardations producing what appears on the profile as negative slopes. The standard low water profile is not well determined, but is of value in indicating about what slopes may be expected at extreme low stage.

Levels.—A considerable amount of leveling was accomplished during the investigation. A good wye level was used, and careful, accurate work was performed. All lines were run in duplicate, and good closures were obtained on all accepted lines. The most important new line was that through the gorge on the American side. This line ran from the precise level bench mark on the old academy at Lewiston to the Pitz Dock; and then up the electric railway tracks in the gorge to the Lake Survey bench mark near the Suspension Bridge gauge. This line connected with the old Lake Survey bench marks at the Whirlpool and on the abutment of the Grand Trunk bridge. A number of new bench marks were established along this line. Another line was run from B. M. Toll at the Canadian end of the upper steel bridge to Boundary Monument No. 20, near the International Railway intake gauge. In addition levels were run to each automatic gauge at least twice during the season, and several minor lines were run.

The descriptions and elevations of the new bench marks are given in Table No. 24. Table No. 25 gives descriptions and elevations of older bench marks in this vicinity.

TABLE No. 24.—*New bench marks established in 1917 in vicinity of Niagara Falls.*

[NOTE.—Elevations are given in feet above mean tide at Sandy Hook and according to the precise level adjustment of 1903.]

B. M. Boundary Monument 19 is the top of the brass plug in the International Boundary Monument No. 19 near Prospect Point. Elevation, 521.753.

B. M. Boundary Monument 20 is the top of the brass plug in the International Boundary Monument No. 20 on the Canadian shore between the river and the highway about 100 feet south of the end of the Horseshoe Falls. Elevation, 518.352.

B. M. Rail is in the Gorge on the American side. It is a square cut in the west edge of the top of a flat rock, 2 feet north and 10 feet east of north switch point of Gorge Railway tracks, 105 paces south of southeast abutment of the Michigan Central Railroad bridge. Elevation, 379.784.

B. M. Stonewall is in the Gorge on the American side. It is a square cut in coping stone of dry masonry retaining wall about 182 paces north of Grand Trunk Railway bridge. Bench mark is 9 paces south of north end of wall. Elevation, 348.416.

B. M. Rapids is in the Gorge on the American side. It is a square cut in the southwest corner of the concrete walk at the Rapids station of the Gorge Railway. Elevation, 334.609.

B. M. Door is in the Gorge on the American side above the Whirlpool on the east side of the Gorge Railway tracks directly in front of north side of the iron door of an old powder house. The bench mark is the top of a round knob chiseled on shelf of rock 2 feet above ground and 2.6 feet from the door jamb. Elevation, 320.450.

B. M. Spring is in the Gorge on the American side just below the Whirlpool between the track and the river at south edge of first group of large rocks projecting into river. It is the top of a knob surrounded by a circular chisel cut on stone in top course of a dry masonry wall. Point is on north end of wall opposite an iron drain pipe. Elevation, 306.269.

B. M. Eye is in the Gorge on the American side opposite the head of Niagara Glen. Bench mark is top of an iron eyebolt set in the north side of a rock projecting from the bank 5 feet outside of outer rail of track, 25 feet north of trolley pole No. 153, and 14 feet north of north end of dry masonry wall. Elevation, 301.995.

B. M. Red is in the Gorge on the American side opposite the center of Niagara Glen between trolley poles Nos. 169 and 170. It is the center of a square chiseled on the highest point of a red boulder on the side of the bank outside of the tracks, 5½ feet from outer face of dry retaining wall and about 3 feet below top of wall. Elevation, 287.257.

B. M. Rock is in the Gorge on the American side opposite the foot of Niagara Glen. It is the center of a square chisel cut on a point of rock projecting from the bank inside of the tracks. It is 4.4 feet east of inner rail of tracks and 20 feet north of trolley pole No. 190. Elevation, 286.348.

B. M. Devils Hole is in the Gorge on the American side abreast of the Devils Hole tablet. It is center of a square chisel cut on flat rock 8.2 feet west of outer rail and 8.2 feet north of northwest corner of abutment of small bridge. Elevation, 277.775.

B. M. Wall is in the Gorge on the American side about two-thirds of the way from the Devils Hole to the transmission line crossing near trolley pole No. 225. It is a square chisel cut on top of the bottom stone in the center of a masonry wall on east side of tracks 20 feet from south end of wall and 4.5 feet south of a drill hole 3 feet above ground in one of the bottom stones of the wall. Elevation, 269.752.

B. M. Transmission is in the Gorge on the American side under the transmission line crossing of the Niagara, Lockport & Ontario Power Co. It is the center of a square chisel cut on top of boulder outside of Gorge tracks and opposite most northerly transmission tower. It is 4.3 feet northwest of trolley pole No. 237. Elevation, 268.792.

B. M. Stone is in the Gorge on the American side north of the transmission line crossing. It is the highest point on a brown stone 2 feet west of the guard rail and 12 paces south of trolley pole No. 250. Elevation, 266.878.

B. M. Lower Gorge Gauge is in the Gorge on the American side 54 paces south of B. M. South. It is a square cut on a large boulder 5 feet from and 2 feet above the water's edge at mean stage. It was opposite the Lower Gorge gauge. Elevation, 253.341.

B. M. South is in the Gorge on the American side opposite Smeatons Ravine. It is the highest point of a stone projecting from the south end of a masonry wall on east side of Gorge tracks. The stone is the second large stone from the bottom of the wall opposite trolley pole No. 264 and 54 paces north of the Lower Gorge gauge. Elevation, 270.857.

B. M. Fishery is in the Gorge on the American side some distance south of Fish Creek. It is the highest point of the reddest stone in the northwest corner of a dry masonry wall topped with concrete on the south side of the stairs leading down to a fish dock between trolley poles Nos. 276 and 277. Elevation, 270.882.

B. M. Fish Creek is in the Gorge on the American side on the Gorge Railway bridge over Fish Creek. It is a square cut on the northwest stone of the north abutment of the bridge, 6 paces south of trolley pole No. 295. Elevation, 284.754.

B. M. Boulder is in the Gorge on the American side north of the Lewiston suspension bridge and near north end of bridge of the Gorge Railway over a deep gulley. It is a square cut on west edge of a boulder 6 feet north of north end of bridge and 2 feet east of guard rail, opposite trolley pole No. 321. Elevation, 306.825.

B. M. Lewiston Gauge is in Lewiston, N. Y. It is a square cut on a large stone projecting a few inches out of the ground and about 50 feet northeast of the northeast corner of Pitz's dock. Elevation, 253.175.

B. M. Pitz is in Lewiston, N. Y. It is the top of a three-fourth-inch gas pipe projecting 2½ inches out of the concrete walk at the southeast corner of the veranda of the "Anglers Retreat" hotel. Elevation, 292.627.

B. M. Monument is in Lewiston, N. Y. It is the northwest corner of the top of a concrete monument about 6 inches square and 8 inches high at the northeast corner of Center and Third Streets. Elevation, 254.873.

TABLE NO. 25.—*Bench marks along the Niagara River established previous to 1917 by the United States Lake Survey, the Board of Engineers for Deep Waterways, and others.*

[NOTE.—Elevations are given in feet above mean tide at Sandy Hook according to the precise level adjustments of 1903. Bench marks marked with an asterisk (*) have had their elevations determined by precise levels, others by ordinary wye levels.]

***P. B. M. Buffalo Lighthouse** is in Buffalo, N. Y., on plinth of the old Buffalo Light (now abandoned) south of the United States pier and in line with Erie Street, being the top of a high point on the east corner and upper surface of plinth. Elevation, 590.101.

***P. B. M. Waterworks** is in Buffalo, N. Y., on stone window sill of center window on the river side of the main building of the old pumping station of the Buffalo waterworks near the foot of Massachusetts Avenue, being the center of a brass bolt leaded horizontally into stone 6 inches from north end of sill and 35 inches above the watertable at the ground, marked thus:

U. S.
⊙
P. B. M.

Elevation, 582.804.

***P. B. M. International Bridge No. 2** is in Buffalo, N. Y., on a projection of stone in fourth course of masonry below bridge seat on north end of east abutment of International Bridge over main channel of Niagara River, being a square cut on stone 5.70 feet below bridge seat and 3.77 feet back of the northwest corner of abutment, the stone above being marked in white paint thus:

U. S. B. M.
88

Elevation, 582.258.

***P. M. B. Guard Lock** is in Buffalo, N. Y., in the center of coping stone on towpath side of guard lock of old Erie Canal, 650 yards below the International Bridge over the Black Rock Ship Canal at Black Rock, being the highest point in a small square cut in the southeast corner of a larger square which

is opposite the hinge of the upper gate and 23 feet below upper end of lock, marked thus: Elevation, 576.454.

[NOTE.—The elevation given on page 2719 of the Chief of Engineers' Report for 1903 is 576.650, which is incorrect.]

P. B. M. Sill is on the stone sill of the basement window on the west side of the office of the Buffalo Smelting Works, at the foot of Austin Street, Black Rock, Buffalo, N. Y., being a smoothed square sunk slightly below the level of the sill. Elevation, 574.762.

**P. B. M. Tonawanda No. 1* is in Tonawanda, N. Y., on stone water table on west side of steeple of Christian Chapel Church, a red brick building on southeast corner of Broad and Seymore Streets, being the intersection of two cross marks cut in center of large square on top of stone. Elevation, 576.214.

**P. B. M. North Tonawanda No. 2* is in North Tonawanda, N. Y., on stone water table 6½ feet south of entrance to the old engine house (marked "1873") of the Tonawanda Iron & Steel Co., situated on the right bank of the Niagara River and on the west side of Main Street, being the top of a small square in the northeast corner of a large square cut in corner of stone. Elevation, 578.822.

**P. B. M. Wheatfield* is in Wheatfield Township, N. Y., on the south end of stone water table on east front of brick schoolhouse, which is in district No. 2, and stands on the right bank of the Niagara River and on the main road 560 yards below the Edgewater Bridge of the International Railway, being a square cut on stone. Elevation, 576.541.

**P. B. M. La Salle No. 1* is in La Salle, N. Y., just south of the La Salle station, on the northwest corner of bridge seat of east abutment of the New York Central Railroad bridge over Cayuga Creek, being the top of a square cut on stone. Elevation, 571.611.

**P. B. M. La Salle No. 2* is in La Salle, N. Y., on the top of the water table at the southeast corner of brick residence belonging to Mr. E. H. Smith, about one-fourth mile west of New York Central Railroad station, on main road along the river front, being the top of a brass bolt leaded vertically into the water table. Elevation, 580.290.

**P. B. M. Echota* is in Niagara Falls, N. Y., on the west end of stone doorsill of west door on south side of the New York Central Railroad station, called "Echota," being the top of a small square in the southeast corner of a larger square cut on the stone. Elevation, 572.922.

**P. B. M. Niagara No. 1* is in Niagara Falls, N. Y., on a stone 5½ inches square, with a small square cut on northwest corner, used as reference stone for the center line of the tunnel of the Niagara Falls Power Plant, and is set in concrete in the gutter about 10 feet northwest of entrance to power house No. 1 of the Niagara Falls Power Co., 10 feet north of north door jamb and 3 feet out from building, being the top of a copper bolt leaded in the center of the stone. Elevation, 566.547.

**P. B. M. Niagara No. 2* is in Niagara Falls, N. Y., on window sill of first window west of northeast corner of Niagara Falls Power Co.'s power house No. 1, being the top of a brass bolt leaded vertically in east end of stone, 5½ feet from front of building, 5 inches back from front edge of window sill, 7 inches west of east side of window and on side of building facing Buffalo Avenue. Elevation, 571.827.

P. B. M. Copper Bolt is in Niagara Falls, N. Y., on the retaining wall on the southerly side of the canal of the Niagara Falls Power Co., 87 feet west of power house No. 2, being the top of a copper bolt leaded into the top of the coping stone. Elevation, 567.216.

T. B. M. Paper is in Niagara Falls, N. Y., on the wall on the northerly side of the intake canal of the Niagara Falls Power Co. at the west end, being the top of the west anchor bolt holding a large iron chock just west of the automatic gauge of the power company. Elevation, 567.288.

P. B. M. Port Day is in Niagara Falls, N. Y., on the west side of the canal of the Hydraulic Power Co. at its head, 25 feet from the Niagara River, 50 feet from the canal, 18 feet from an iron electric light pole, 6 feet from a double boxwood tree, being the top of a conical iron bolt leaded into the top of a cut stone 6 inches square projecting 4 inches above the surface of the ground. Elevation, 567.165.

P. B. M. Park is in Niagara Falls, N. Y., on the northeast corner of the administration building, New York State reservation, directly under north window on the east side of the building, 10.3 feet from the northeast corner,

being the top of a brass bolt leaded vertically into the water table, marked thus

U. S.



B. M.

Elevation, 556.406.

B. M. Triangle Terrapin is in Niagara Falls, N. Y., at the Goat Island end of the Horseshoe Falls, being the top of a brass bolt leaded vertically into the large bowlder known as "Terrapin Rock." The word "Terrapin" is cut in rude letters around the bolt. Elevation, 511.119.

B. M. Terrapin Gauge is in Niagara Falls, N. Y., at the Goat Island end of the Horseshoe Falls, being the top of a rounded knob on a small projecting ledge on the south side of "Terrapin Rock." Elevation, 509.665.

P. B. M. Arch is in Niagara Falls, N. Y., on the retaining wall at the east abutment of the upper steel arch bridge, being the top of a brass bolt leaded vertically into the stone, 20.4 feet southwest of the southwest edge of bridge plate, 1.55 feet from outer edge of wall, and 29.1 feet from southwest end of wall, marked

U. S.



B. M.

Elevation, 361.172.

P. B. M. Toll is in Niagara Falls, Ontario, being a point on stone in the fourth course below middle window on the west side of the Canadian customs and toll station at the west end of the upper steel arch bridge. Elevation, 525.918.

P. B. M. Chippawa is in Chippawa, Ontario, being a square cut on top of stone water table at southwest corner of Baltimore Hotel, on the corner of Front and Bridgewater Streets. Elevation, 571.670.

P. B. M. Black Creek is in Black Creek, Ontario, being a square cut on the southwest corner of upper plate under the northwest corner of the highway bridge over Black Creek. Elevation, 570.554.

P. B. M. Bridge No. 1 is in Niagara Falls, N. Y., being the top of a brass bolt leaded vertically into the top of a large bowlder at south end of retaining wall at abutment of Michigan Central Railroad bridge over Niagara River. The bolt is 15 feet from abutment and 113 feet from inclined railway building, marked thus:

P. B. M.



U. S.

Elevation, 363.580.

P. B. M. Bridge No. 2 is at Niagara Falls, N. Y., 6 feet from the water's edge, 362 feet south of the south side of the abutment of Michigan Central Railroad bridge in the gorge, being the top of a brass bolt leaded vertically into a large flat rock marked

U. S.



P. B. M.

Elevation, 345.284.

**P. B. M. Suspension Bridge* is in Niagara Falls, N. Y., in the northwest corner of the Suspension Bridge passenger station of the New York Central Railroad, being the center of a brass bolt leaded horizontally into center of seventh stone above the water table, 43 inches above the platform and 6 inches south of the northwest corner of the building. Elevation, 584.377.

P. B. M. Whirl is on the American side of the Niagara Gorge at the whirlpool on the ledge of flat rock extending into the river at the point, only a few inches above mean stage of the river (often submerged), 20 feet from the west edge of the ledge, 35 feet from the north edge and 35 feet from the corner, being the top of a brass bolt leaded vertically into the rock and marked

B. M.



WHIRL

Elevation, 294.426.

P. B. M. Whirlpool is on the Canadian side of the Niagara Gorge at the whirlpool, 750 feet from point at entrance to whirlpool, 275 feet south of a

small creek, being the top of an iron bolt leaded vertically into the top of rock ledge 1.9 feet from its water edge, marked

U. S.
 ○
 P. B. M.

When established in 1906 the above description was written and the elevation was reported as 297.040. In 1909 it was found that the part of the rock on which the bench is situated had been broken from the ledge forming a large irregular fragment and that the elevation had been somewhat changed. In 1917 levelling from P. B. M. Pool determined the elevation to be 296.977.

P. B. M. Pool is on the Canadian side of the Niagara Gorge at the Whirlpool, about 40 feet north of P. B. M. Whirlpool, on the same ledge of rock (not broken off here) close to the water's edge, being the top of a brass bolt leaded vertically into the ledge, marked

B. M.
 ○
 POOL

Elevation, 297.731.

* *P. B. M. University* is about 2 miles north of Niagara Falls, N. Y., and 65 yards east of top of Gorge of Niagara River, in west corner of main building of Niagara University, being the center of a brass bolt leaded horizontally into stone 4½ inches east of corner and 20 inches above ground. Elevation, 589.352.

* *T. B. M. No. 31* is in Lewiston Heights, N. Y., on top of retaining wall on south side of wagon road, 10 feet north of center of track of the New York Central Railroad and 39 feet east of northeast corner of Lewiston Heights Station, being the top of a small square cut on large stone. Elevation, 530.919.

* *P. B. M. Lewiston Heights No. 2* is 111 yards east of the center of Lewiston Heights Station, N. Y., in face of solid ledge rock on upper side of wagon road leading down from Lewiston Heights Station to Lewiston, being the center of a brass bolt leaded horizontally in vertical face of rock, 21 inches below top of ledge, and marked thus, in 3-inch letters:

U. S.
 ○
 P. B. M.

Elevation, 506.404.

* *P. B. M. Lewiston* is in Lewiston, N. Y., at corner of Center and Ninth Streets, on the northwest corner of stone door sill of north door of west wing of old Seminary Building, being a square cut on stone. Elevation, 401.331.

* *P. B. M. Murphy* is in Lewiston, N. Y., on south side of Center Street, between Fourth and Fifth Streets, being a square cut on water table of northeast corner of foundation of brick store owned by Eugene Murphy. Elevation, 363.34.

Topography.—A general topographic map was prepared showing the Niagara River from above Cayuga Island to below Lewiston. Along the Canadian shore a strip of country about half a mile wide is depicted, while on the American side the map covers a triangle about 6 miles wide and 7 miles long. This area includes the ground covered by all the American power development projects of merit which have been proposed. The map is shown on plates Nos. 13 and 14.

For the most important part of this map a very careful transit and stadia survey was made. The area covered is roughly bounded by the Military Road, Fish Creek, the top of the Gorge, Bloody Run, Whirlpool Avenue, Sugar Street, and the New York Central Railroad tracks. This amounts to about 12 square miles. The work was thoroughly and carefully performed. All details that properly should show on a 1:10000 map were located, and enough elevations were taken for the plotting of contours with a vertical interval of 2 feet.

The rest of the map was compiled from various sources, including maps of the Board of Engineers for Deep Waterways, the Lake

Survey, the Geological Survey, the city of Niagara Falls, and the two American power companies, corrections and additions being obtained by fragmentary surveys and reconnaissance.

A special survey was made of the American bank of the Gorge from above the Devils Hole to below Fish Creek. This was done by transit and stadia, supplemented by a "hand transit." The results are incorporated in the large topographic map, and are also given separately on a larger scale on plate No. 16. Practically all the proposed lower river power-house sites are located within the limits of this survey.

The transit and stadia surveys involved a large number of closed traverses which were tied in horizontally to several existing triangulation stations, and vertically to several precise bench marks. The latitude, longitude, and elevation of each transit station or stake was computed carefully, and the point plotted accurately. All side shots were plotted with large Colby protractor. By such methods a map of great accuracy has been obtained.

Rock Soundings.—In making estimates of the cost of a power canal from the upper river to the edge of the lower Gorge it was necessary to know the depth of earth that would be found on top of the rock along the various proposed routes. The only data available was a line of rock soundings near Military Road made by the Deep Waterways Board, and a few records of city sewer surveys at Niagara Falls. To supplement this data an extensive rock survey was made over the areas between the Military Road and Sugar Street.

The soundings were made with a series of hexagonal tool steel rods. The first rod was $1\frac{1}{2}$ inches in diameter and 4 feet long. It was driven into the ground with sledges until only about half a foot remained above ground. It was then pulled out by means of a special "puller," consisting of a series of levers, and the next rod was inserted in the hole. This rod was $1\frac{1}{2}$ inches in diameter and 7 feet long, and was driven and pulled in the same manner.

This process was continued, each rod being an eighth of an inch smaller and 3 feet longer, until rock was struck. The longest rod used was three-fourths inch in diameter and 25 feet long. A longer rod of five-eighths inch size was provided, but could not be used because it was too flexible to be inserted in the hole without use of a small gin pole or derrick.

The work was carried on under great difficulties throughout the coldest winter ever recorded in this region. Photographs Nos. 69 to 71 illustrate the process. No. 69 shows a rod being driven and No. 70 shows the pulling machine in operation. The rock surface was overlaid with a foot or two of hardpan and boulders, and this often bent and twisted the rods so that two heavy screw jacks had to be used to pull them, as is shown in photograph No. 71.

Altogether 60 rock soundings were made. They are plotted on the general topographic map, plates Nos. 13 and 14.

Other field work performed included an examination of the Welland Canal, a reconnaissance of the route of the proposed Erie & Ontario Sanitary Canal, and various inspections of the new construction under way on both sides of the river at Niagara Falls.

The most difficult and important part of the office work was the designing and estimating of proposed power development projects for the use of water diverted from Niagara River. A great deal of

time was spent on this work, studying the situation and the various problems involved, consulting informally with engineers, contractors, and others familiar with these matters, making outline designs, and preparing and checking estimates. In this connection a careful study was made of all the reports submitted by those interested in Niagara power development. The detailed description of this work is given in Section F of this report.

Next in importance to the power projects was the matter of remedial works above the Horseshoe Falls. A large amount of time was spent in the study of this problem and in the preparation of outline plans and estimates. These are given in Section E.

Other office operations not already specifically noted included reduction and study of data pertaining to the Chicago Drainage Canal, and the assembling and examination of data pertaining to various phases of the investigation. The preparation of the report has been a task requiring a large amount of time.

W. S. RICHMOND.

APPENDIX C.

PRESERVATION OF SCENIC BEAUTY OF NIAGARA FALLS AND OF THE RAPIDS OF NIAGARA RIVER.

[Lieutenant Jones's report.]

AUGUST 26, 1919.

From: First Lieut. Albert B. Jones, Engineers, United States Army.
To: The Division Engineer, Lakes Division, Buffalo, N. Y.
Subject: Report on preservation of scenic beauty of Niagara Falls and of the rapids of Niagara River.

There is submitted herewith report on preservation of scenic beauty of Niagara Falls and of the rapids of Niagara River.

ALBERT B. JONES,
First Lieutenant, Engineers.

1. THE PROBLEM.

Preliminary.—The Falls of Niagara are probably the most famous scenic marvel in the world. Except for the distant and inaccessible Zambesi Fall in Africa, no other cataract approaches it in majesty and power. The staggering rush of this great volume of water, the roar of its descent, and the rainbow-marked column of ascending spray form a spectacle which for 240 years has excited the awe and admiration of all beholders. No place in this country is so well known to Europeans, and even visitors from China and Japan are anxious to view the famous cataract. Neither is the place without honor in its own country. No great natural feature in the United States is visited by as many Americans as Niagara Falls. The officers in charge of the New York State reservation estimate the annual number of visitors at one and one-half million persons. Many of these come from a great distance, and their average expenditure for the trip is estimated at \$25 apiece, or a total of \$37,000,000 per annum.

The money these sightseers spend each year is, in a measure, an indication of the value of the scenic beauty of the Falls. These people feel that to have experienced the sublimity and grandeur of the cataract and its surroundings has been an adequate return for an expenditure of \$37,000,000 per year. Such an expenditure, by the people of a Nation commonly accused of a money-grubbing commercialism is surely a sign of our æsthetic salvation. In this way the Falls are a great national asset, intangible, it is true, and not to be measured in dollars and cents, but nevertheless of immense value to the spiritual and artistic life of the Nation. The destruction or serious defacement of this great spectacle for the sake of developing

water power, or for any other object, would be a piece of intolerable vandalism to which the people of this country would never submit.

Fifteen years ago it appeared possible that such a defacement was impending and water-power development was accordingly checked by the Burton Act and the subsequent treaty with Great Britain. By its terms the Burton Act was a temporary measure. It was like the temporary injunction issued by courts of equity which forbids a certain act to be done until investigation shows whether or not its consequences will be harmful to the plaintiff. The investigation has now been made, and it remains only to determine what are the proper limits that should be placed upon power development to prevent damage to the scenic beauty of the Falls.

The water power also has its imaginative and spiritual appeal. It represents in a most dramatic way the triumph of man over matter. The very name "Niagara" has become proverbial as representing the great forces of nature in one of their more irresistible and uncontrollable manifestations and yet a part of this awe-inspiring force has been harnessed to the service of man. The record of the energy and persistence of the pioneers who developed the great hydraulic and electric installations at Niagara forms a bright page in the history of science and engineering.

Aside from the direct monetary value of the electric power, these developments have also great value as a cultural and civilizing force. The presence of large amounts of cheap power at Niagara has been the chief moving force behind the recent advance of the electrochemical industries, and this advance has been revolutionary. Compare conditions now with those of 1890, when the first large power house was building. Then aluminum was a laboratory curiosity worth \$10 or \$12 a pound; now it is an every-day necessity and costs little more than copper. Then steel was a simple alloy of iron and carbon; to-day nearly every tool of the mechanic is hardened or toughened with silicon, chromium, titanium, or some other product of the electric furnace. Then emery and graphite were valuable minerals whose visible supply was rapidly decreasing; now carborundum and artificial graphite are driving the natural supply from the market by their cheapness and uniformly high quality. To these must be added calcium carbide and acetylene gas, liquid chlorine, artificial gems, and many other products quite unknown or not commercially available 28 years ago. These things have revolutionized our way of living in many ways, ranging from cookery to transportation. The farmer stimulates his crops with fertilizers seized from the atmosphere by Niagara power. The food he grows is cooked in vessels of Niagara aluminum with water purified by liquid chlorine from the same source. It is no exaggeration to say that modern aeroplanes and motor cars would be impossible without the aid of the aluminum, abrasives, and alloy steels developed by Niagara power.

These things belong to the past. What beneficial results would flow from a further development of this natural resource no one can tell, but there is no reason to expect the future to be less productive than the past. Rather does science advance by geometrical progression, using the gains of to-day as the basis for a broader advance on the morrow. Surely we owe it to ourselves and to posterity to de-

velop this magic power to the utmost limits that are possible without committing the sacrilege of harming nature's great temple of beauty. It may well be that while doing so we can also repair some damage that has already been done by the hand of man and by that process of natural decay which tends to destroy all waterfalls.

In short, our problem reduces itself to this: What can be done to repair existing damage to the beauty of the Falls and how much more power can be developed without doing further damage?

Description of the Falls and rapids.—For the study of this problem a thorough knowledge of the different parts of the Falls and rapids is necessary. In Section A of this report will be found a description of the river as a whole with its relations to the adjacent lakes. The features having a scenic interest will now be described in more detail. The items described will all be found on the topographic map on photographs 13 and 14 of this report. In photographs Nos. 72 to 129 are a collection of views of the most important scenic features under various conditions of stage and diversion.¹ Photograph No. 72 shows summer and winter panoramic views taken from the Canadian edge of the Gorge a little ways above the bridge. Photograph No. 73 is another panorama taken from "Falls View." The other photographs are pictures of the individual features.

The upper Niagara River down to Port Day is a stream of no particular scenic value. Just below this point Goat Island divides the stream into two channels, the right hand or northeasterly, of which forms the "American or Goat Island Rapids." Photographs Nos. 74 to 76 show these rapids. This is one of the most beautiful rapids, especially the part below the bridge, not shown in the pictures. It consists of a series of cascades and chutes divided up by a number of small wooded islands. The contrast between the dark green of the islands and the foaming breakers and white waters of the rapids is very beautiful, especially in bright weather. These rapids are 2,500 feet long and from 400 to 1,200 feet wide. Their average flow under present conditions is perhaps 9,000 cubic feet per second.

Southeast of Goat Island lies the "Canadian or Horseshoe Rapids." These begin with a series of long cascades extending from the Three Sister Islands across the stream to the Dufferin Islands. Below the cascades the rapids flow swiftly down a wide and steep incline of rock; some parts are quite shallow. While some views of this rapid give a sensation of power and swiftness, there is but little of beauty or grandeur in it except at the cascades. The Canadian Rapids are shown in photographs Nos. 78 to 81 and still better in photograph No. 73. They are about 3,000 feet long and the width varies from 3,500 to 1,200 feet. Under present conditions the flow just above the Falls is about 150,000 cubic feet per second.

At the foot of the American Rapids the water falls over a steep, sheer, and rocky cliff into the Gorge, forming the "American Falls." This is probably the most beautiful and best known of the rapids and can be seen to advantage from Prospect Point. It is the most often selected for reference in the International Bridge, and it is shown in photograph



¹ See also supplementary report.

The crest line is about 1,000 feet long and only slightly curved. Over this crest the water rushes with an average depth of $1\frac{1}{2}$ feet and an average velocity of 6 feet per second and plunges vertically down onto the huge rocks piled at the foot of the cliff. The height of the fall is 167 feet. At the southwest end Luna Island separates the last 60 feet from the main fall. This section is known as the "Luna Fall" or "Bridal Veil Fall." Prospect Point is the best viewpoint for the American Falls and, being easy of access, is the most visited point of Niagara. Here the visitor finds the whole roaring rush and power of the Falls at his very feet. A still greater effect of irresistible power is felt when this cataract is viewed from the talus slope at the foot of the cliff below Prospect Point. Here the rock itself trembles from the impact of the falling waters.

The "Horseshoe or Canadian Fall" lies south and west of the American Falls and is separated from it by Goat Island. This fall has a tremendous flow of water, sixteen times as much as the American Falls, but for several reasons it fails to make a proportionate effect. The original horseshoe shaped crestline which gave it its name has gradually been eaten away until now the plan is a curved V as shown on plate No. 18. The apex of this notch is not ordinarily visible from any point of view. The greater bulk of the water rushes into this notch and sends up a cloud of spray and mist which nearly always forms an impenetrable curtain in front of this part of the fall.

Photographs Nos. 91 to 104 and Nos. 72 and 73 show different views of the Horseshoe Falls, but it was impossible to get one showing the face of the Falls at this notch. Even without the spray the shape of the crest is such that only a distant and foreshortened view would be possible.

At ordinary stages the parts of the Falls adjacent to the notch show a spectacle comparable to the American Falls, but only to be seen from a distance. The ends are the only parts which can be approached by the observer and these show only a meager display. The flow is not continuous along their crest, but is broken in several places. At very low stage many stretches of bare rock are visible and the flow is reduced to small detached streams; see photographs Nos. 95 and 97, observing that these were taken at a moderately low stage and that conditions are often much worse than the pictures show.

The crest line of the Horseshoe Falls is 2,600 feet long. The height is 162 feet and the average flow under present conditions is about 150,000 cubic feet per second.

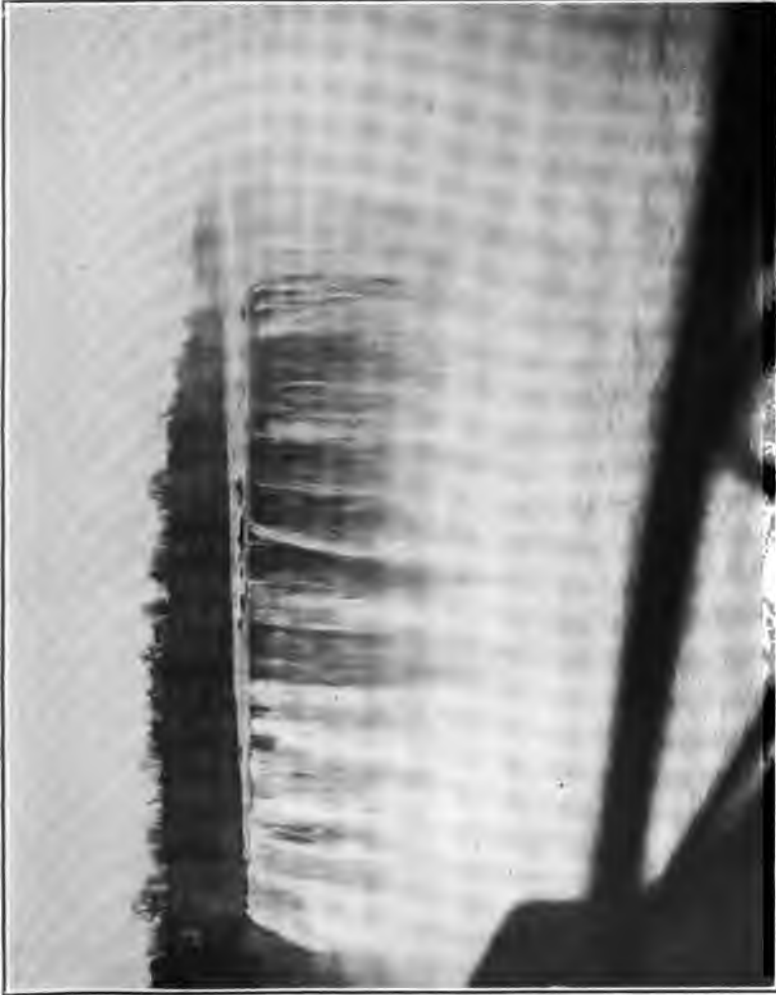
A short distance below the Falls is the stretch of quiet from the same source, about the "Maid-of-the-Mist Pool." This is aeroplanes and motor cars. 72, 73, and 105. The Pool is a body of the aluminum, abrasives, water extending from the foot of the Falls power.

These things belong to the future. The water flow from a further development of the Falls. Elsewhere tell, but there is no reason to expect the new highway bridge, where it than the past. Rather does science advance. Falls Power Co.'s tunnel. sion, using the gains of to-day as the basis for the American Falls and the morrow. Surely we owe it to ourselves to clear the water clear across to the power plants is dis-





Photograph No. 100 (3.25 p. m., Nov. 7, 1917).—EAST END OF HORSESHOE FALLS, FROM CANADIAN SIDE.
River discharge 213,000 cubic feet per second. Approximate flow over Falls 165,000 cubic feet per second.



Photograph No. 101 (2.35 p. m., Oct. 30, 1917).—EAST END OF HORSESHOE FALLS, FROM CANADIAN SIDE
River discharge 272,000 cubic feet per second. Approximate flow over Falls 220,000 cubic feet per second.



Photograph No. 102 (11:35 a. m., Dec. 3, 1917). EAST END OF HORSESHOE FALLS, FROM GOAT ISLAND.
River discharge 205,000 cubic feet per second. Approximate flow over Falls 155,000 cubic feet per second.



Photograph No. 103 (12.30 p. m., Nov. 7, 1917).—EAST END OF HORSESHOE FALLS, FROM GOAT ISLAND.
River discharge 210,000 cubic feet per second. Approximate flow over Falls 160,000 cubic feet per second.



Photograph No. 104 (11.45 a. m., Oct. 30, 1917).—EAST END OF HORSESHOE FALLS, FROM GOAT ISLAND.
River discharge 294,000 cubic feet per second. Approximate flow over Falls 245,000 cubic feet per second.



Photograph No. 105.—MAID-OF-THE-MIST POOL, FROM THE MICHIGAN CENTRAL BRIDGE.



Photograph No. 106 (11.15 a. m., Dec. 18, 1917).--HEAD OF WHIRLPOOL RAPIDS, FROM GRAND TRUNK RAILWAY BRIDGE.
River discharge* 205,000 cubic feet per second.



Photograph No. 107 (12.55 p. m., Dec. 7, 1917).—HEAD OF WHIRLPOOL RAPIDS, LOOKING UPSTREAM.
River discharge 203,000 cubic feet per second.



Photograph No. 108 (10.20 a. m., Nov. 8, 1917).—HEAD OF WHIRLPOOL RAPIDS, LOOKING UPSTREAM.
River discharge 217,000 cubic feet per second.



Photograph No. 109 (3.20 p. m., Oct. 30, 1917).—HEAD OF WHIRLPOOL RAPIDS. LOOKING UPSTREAM.
River discharge 267,000 cubic feet per second.



Photograph No. 110 (1.10 p. m., Dec. 7, 1917).—WHIRLPOOL RAPIDS, LOOKING UPSTREAM.
River discharge 203,000 cubic feet per second.



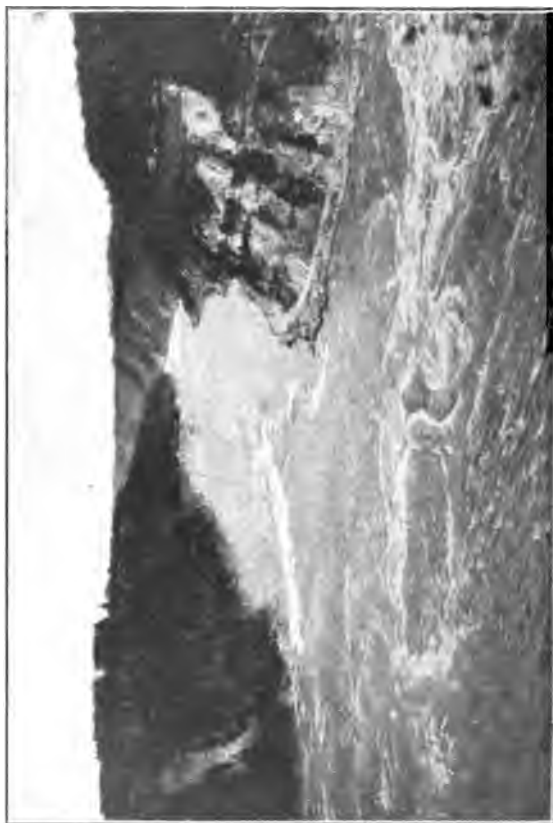
Photograph No. 111 (10.40 a. m., Nov. 8, 1917).—WHIRLPOOL RAPIDS. LOOKING UPSTREAM.
River discharge 217,000 cubic feet per second.



Photograph No. 112 (3.35 p. m., Oct. 30, 1917). WHIRLPOOL RAPIDS, LOOKING UPSTREAM.
River discharge 267,000 cubic feet per second.



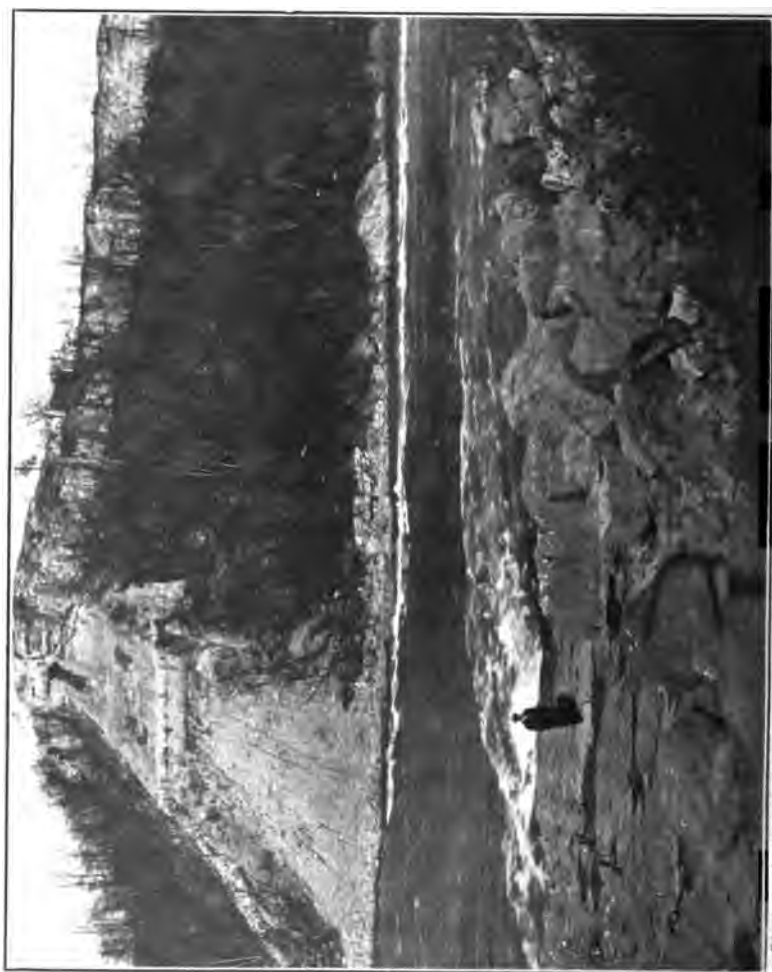
Photograph No. 113 (10.32 a. m., Nov. 8, 1917).—NEAR LOWER END OF WHIRLPOOL RAPIDS.
River discharge 217,000 cubic feet per second.



Photograph No. 114.—THE WHIRLPOOL AND THE LOWER RAPIDS, FROM CANADIAN CLIFF.



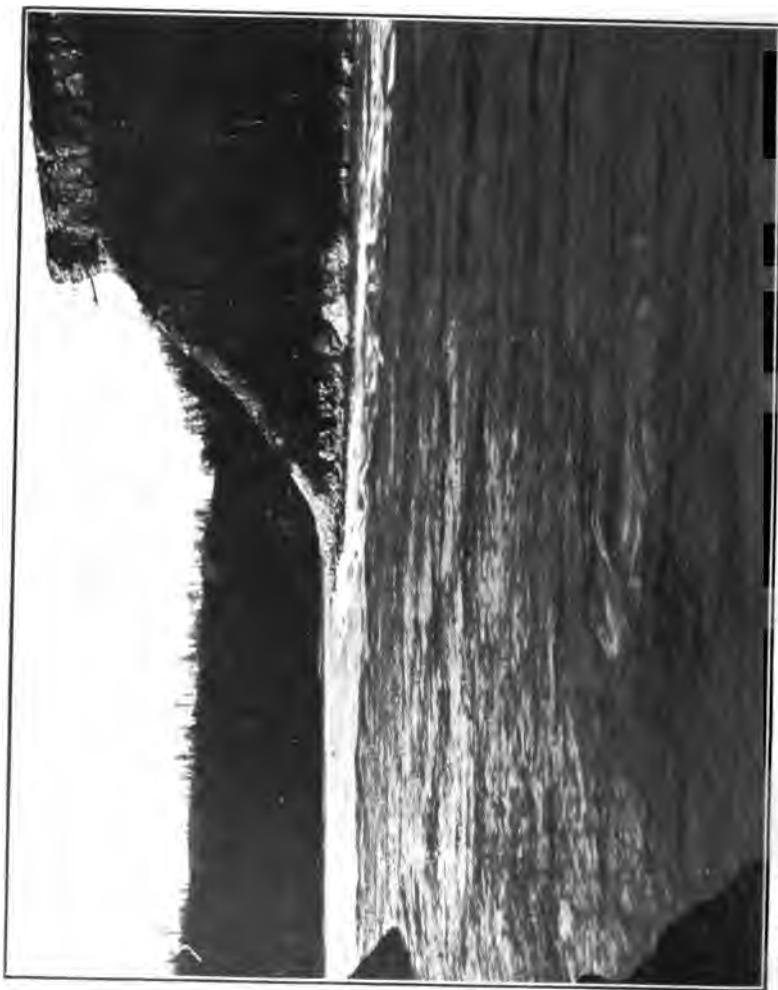
Photograph No. 115 (1.25 p. m., Dec. 7, 1917).—OUTLET OF WHIRLPOOL AND HEAD OF LOWER RAPIDS.
River discharge 203,000 cubic feet per second.



Photograph No. 116 (10.55 a. m., Nov. 8, 1917). OUTLET OF WHIRLPOOL AND HEAD OF LOWER RAPIDS.
River discharge 217,000 cubic feet per second.



Photograph No. 117 (1.40 p. m., Dec. 7, 1917).—OUTLET OF WHIRLPOOL, LOOKING UPSTREAM.
River discharge 203,000 cubic feet per second.



Photograph No. 118 (11.25 a. m. Nov. 8, 1917).— OUTLET OF WHIRLPOOL, LOOKING UPSTREAM.
River discharge 217,000 cubic feet per second.



Photograph No. 119 (3.55 p. m., Oct. 30, 1917).—OUTLET OF WHIRLPOOL, LOOKING UPSTREAM.
River discharge 266,000 cubic feet per second.



Photograph No. 120 (2.20 p. m., Dec. 7, 1917).-- LOWER RAPIDS AT HEAD OF FOSTERS FLATS.
River discharge 203,000 cubic feet per second.



Photograph No. 121 (2.10 p. m., Dec. 7, 1917).—LOWER RAPIDS ABREAST FOSTERS FLATS, LOOKING UPSTREAM.

River discharge 203,000 cubic feet per second.



Photograph No. 122 (10.50 a. m., Nov. 8, 1917).-- LOWER RAPIDS ABREAST FOSTERS FLATS, LOOKING UPSTREAM.

River discharge 217,000 cubic feet per second.



Photograph No. 123 (4.30 p. m., Oct. 30, 1917).- LOWER RAPIDS ABREAST FOSTERS FLATS, LOOKING UPSTREAM.

River discharge 266,000 cubic feet per second.



Photograph No. 124 (1.58 p. m., Dec. 7, 1917).—HEAD OF FOSTERS FLATS. LOOKING DOWNSTREAM.
River discharge 203,000 cubic feet per second.



Photograph No. 125 (2.30 p. m., Dec. 7, 1917).—LOWER RAPIDS, FOOT OF FOSTERS FLATS, LOOKING
DOWNSTREAM.

River discharge 203,000 cubic feet per second.

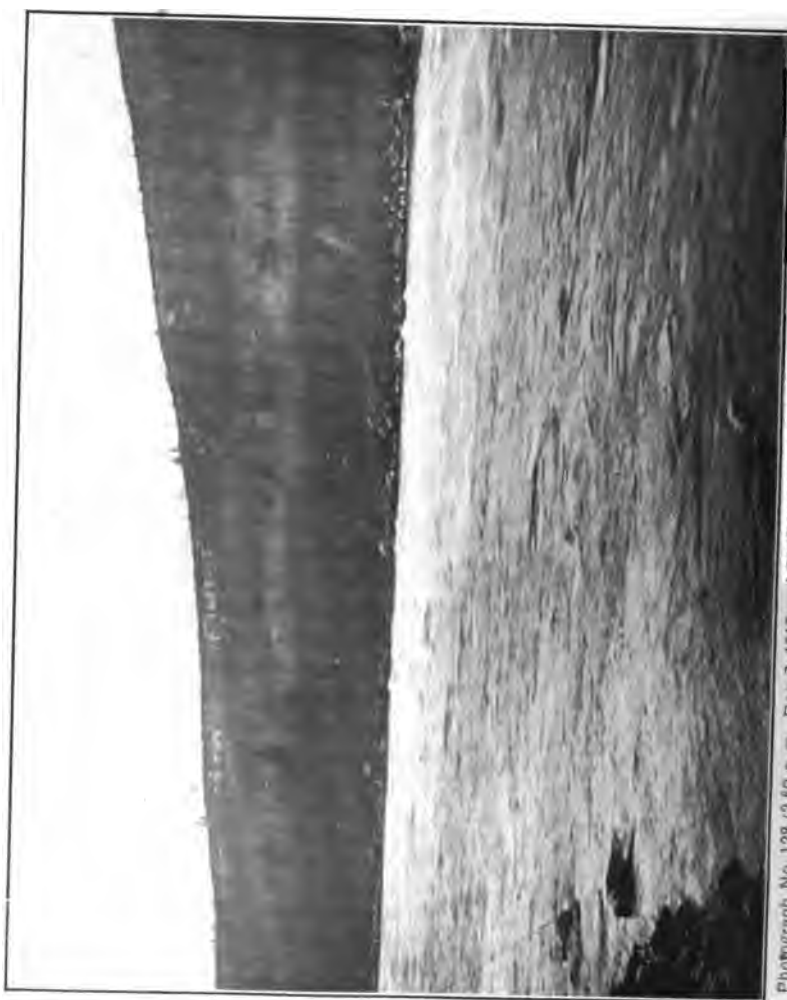


Photograph No. 126 (12.00 Noon, Nov. 8, 1917).-- LOWER RAPIDS, FOOT OF FOSTERS FLATS, LOOKING
DOWNSTREAM.
River discharge 217,000 cubic feet per second.



Photograph No. 127 (4.22 p. m., Oct. 30, 1917).—LOWER RAPIDS, FOOT OF FOSTERS FLATS, LOOKING
DOWNSTREAM.

River discharge 266,000 cubic feet per second.



Photograph No. 128 (2.50 p. m., Dec. 7, 1917).—LOWER RAPIDS FOOT OF POSTERS FLATS, LOOKING UPSTREAM.

River discharge 202,000 cubic feet per second.



Photograph No. 129 (3.35 p. m., Dec. 7, 1917). —FOOT OF LOWER RAPIDS, SHOWING "LOWER GORGE GAUGE."

River discharge 202,000 cubic feet per second.



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charged into this pool and three of the power houses are on its banks at the foot of the cliffs.

The Maid-of-the-Mist Pool is 12,000 feet long. It has an average width of 850 feet and a maximum of 1,400. Its greatest depth is not known, but a sounding of 192 feet has been recorded.

At the foot of the Maid-of-the-Mist Pool the river narrows sharply to a width of about 360 feet at the railroad bridges. The next mile of the river is known as the "Whirlpool Rapids." These are the most spectacular rapids. The width is only about 400 feet except near the lower end, where it widens to 800. The cliffs are from 230 to 270 feet high and are very precipitous, especially on the American side. The bottom of this deep gorge is obstructed by great masses of rock, over which the water dashes tumultuously, reaching velocities of more than 30 feet per second. Breakers and standing waves are formed on a larger scale than anywhere else. Photographs Nos. 106 to 113 illustrate these rapids.

At the foot of these rapids is the "Whirlpool." This is an immense elliptical basin 1,700 feet long and 1,200 feet wide surrounded by banks 280 feet high. The water enters from the southeast and circles around rapidly in a counterclockwise direction, eventually making its escape through the outlet to the northeast by passing *under* the incoming stream. Logs and other drift frequently circle the Whirlpool for weeks before making their escape. The deepest sounding that has been made in the Whirlpool is 126 feet. No comprehensive view of the Whirlpool is available, but photographs Nos. 116 to 119, taken to show the head of Lower Rapids, give glimpses of the Pool.

From the Whirlpool the water rushes violently through the narrow gap shown in plates 115 to 119 and enters the "Lower Rapids." These are a little more than 2 miles long. They are similar to the Whirlpool Rapids except that the velocities are not quite so great and the cliffs are less steep. For the first half mile the width is about 600 feet. Below this the Gorge is obstructed by a mass of rock on the Canadian side known as "Fosters Flats" or "Niagara Glen." For half a mile abreast of the flats the rapids are almost equal to those above the Whirlpool. The narrowest part of the river, in fact, the narrowest part of the Great Lakes system from Duluth to the sea occurs near the head of Fosters Flats, where the width is about 310 feet. The portion of the rapids below the flats is from 500 to 800 feet wide, with increasing depths and diminishing velocities until some distance above the Suspension Bridge the term "rapids" is hardly applicable and below the bridge the current is quite moderate and the river is navigable for the largest boats. The cliffs of the lower gorge reach a maximum height of 310 feet. Pictures of the Lower Rapids are shown on photographs Nos. 120 to 129.

Effect of stage and of diversions.—The amount of water flowing through the Niagara River depends primarily upon the elevation of Lake Erie at Buffalo; the higher the lake the greater the flow in the river. This relation may be expressed with sufficient accuracy for present purposes by the formula—

$$Q=3,904 (H-558.37)^{3/2}$$

where Q is the discharge of the river in cubic feet per second and H is the elevation of Lake Erie at the Buffalo gauge. This formula is

derived from current meter measurements made from the International Bridge at Black Rock by the United States Lake Survey and has been checked by measurements at two other sections. An automatic water gauge has been maintained at Buffalo since 1898. By combining the records of this gauge with the formula given above the fluctuations of the river flow can be studied.

In the 21 years since this gauge was established the yearly mean discharge has varied from a minimum of 184,000 cubic feet per second in 1901 to a maximum of 218,000 cubic feet per second in 1913. The variations in the daily mean flow are much larger, but values greater than 235,000 cubic feet per second or less than 160,000 are very rare, seldom occurring oftener than two or three times a year. During heavy gales the elevation at Buffalo undergoes very great fluctuations which last only a few minutes. On December 7, 1909, at 5.28 p. m., the gauge recorded 580.28, and on February 1, 1915, at 6.54 p. m., it was 567.38. These are the maximum and minimum heights in the gauge book. Applying the formula given above would indicate corresponding discharges of 400,000 and 106,000 cubic feet per second respectively. As a matter of fact, it requires several hours for the effect of a large change in the Buffalo gauge to reach the Falls, and as these extremes last for only a few minutes the maximum and minimum flows at the Falls were probably much more moderate than these figures would indicate.

By computing the elevation at Buffalo from that recorded at Cleveland it is possible to use a longer series of years. Using the 51 years beginning in 1861, the mean discharge of the Niagara River is 207,000 cubic feet per second. This has been adopted as the standard for this report. It corresponds to the gauge heights shown on the profile on plate No. 11.

The effect of diversions of water from the river is very nearly the same as the effect of a low stage of Lake Erie except that only the portion of the river between the point where the water is taken out and the point where it is returned is affected. The present diversions for power affect the appearance of the American and Canadian Rapids and the American and Horseshoe Falls, but not the Whirlpool Rapids or the Lower Rapids. The proposed developments with a 300-foot head would affect these also, as do the diversions of the Welland Canal, the New York State Barge Canal, and the Chicago Drainage Canal.

Photographs Nos. 74 to 127 show the appearance of the different falls and rapids at various stages. One set was taken at extremely high stage and one at about the mean stage. It was unfortunately impossible to get a set at extremely low stage, although no effort was spared, and the third set shows conditions only a little below mean stage.¹ Each picture is marked with the date and time when it was taken, and the computed flow of the river at that time. In addition, those showing the Falls or the rapids above the Falls are marked with the computed flow over the Falls. In studying these pictures it should be borne in mind that the average flow of the river is 207,000 cubic feet per second; that originally this all went over the Falls, but that at present the power diversion amounts to about 50,000 cubic feet per second, and the flow over the Falls averages 157,000.

¹ See also supplementary report on p. 281.

Photographs Nos. 74 to 80 show the Canadian and American Rapids above the falls with the flow over the Falls ranging from 155,000 to 245,000 cubic feet per second. It appears that change of stage does not have a very great effect on the beauty of the rapids. The American Rapids looks better in the extreme high stage of photograph No. 76, but this is partly due to the fact that better lighting conditions on that day gave a better photograph. The same is true of photograph No. 80 of the Canadian Rapids. The only place whose beauty suffers badly is the northwest corner of the Canadian Rapids, where the unsightly shoal shown in photograph No. 81 is much more conspicuous at low stage.

The American Falls is shown in photographs Nos. 82 to 90. It is rather sensitive to changes of stage. Photographs Nos. 87 and 89 show this particularly well despite the fact that No. 89 is a very poor photograph because of the spray. At the low stage the crest is but thinly covered, and the water shows an angular drop as it passes over. At the high stage the rock ledges of the crest are practically invisible and the water leaps into the Gorge in a beautiful parabolic curve. Photograph No. 90 is taken from a higher point of view and shows the thinness of the Falls at low stage still more plainly. On the not uncommon days when the flow over the Falls is reduced to 140,000 cubic feet per second this affect is, of course, very much worse than the pictures show.

Of all the natural features at Niagara the Horseshoe Falls is the one most affected by change of stage. This is illustrated in photographs Nos. 91 to 104. The appearance of the "notch," as far as it is visible at all, is not appreciably different at high stage or at low, but on either end of the Falls the effects are striking. Photograph No. 98 shows both ends of the Falls from Goat Island at a very high stage when the flow over the Falls was 245,000 cubic feet per second. At both ends there is a continuously buried crest line with a rush of white water over it comparable with the American Falls at its best. Photograph No. 96 shows the west end and photographs Nos. 99, 101, and 104 show the east end on the same day. Compare these with the pictures taken from the same points on days when the flow over the Falls was reduced to 155,000 or 165,000. Photographs Nos. 102 and 103 show the broken crest line and separated streams at the east end where at high stage there was the splendid display of photograph No. 104. Photographs Nos. 97, 98, and 100 show how the bare black rocks of the cliff are exposed at low water, while in Nos. 99 and 101 they are concealed behind their full veil of falling water. Photograph No. 95 is the most striking of all.

It must be emphasized that although this picture and No. 96 include somewhat different amounts of background, they were taken from exactly the same spot. If the right-hand part of No. 95 be covered up as far as a vertical line through the left-hand ventilator on the roof of the power house, these two are exactly comparable. The slimy, unsightly ledges of rock in the foreground of 95 form the crest over which the magnificent cataract of 96 is plunging. It should also be noticed that photograph No. 95 shows several thousand cubic feet per second more than the average flow under present conditions, and that stages a great deal lower than this are not at

all uncommon.¹ The appearance of the face of this part of the Falls at high and mean stage is shown on Nos. 92 and 93.

The Maid-of-the-Mist Pool is not noticeably changed in appearance by change of stage, and the same is true of the Whirlpool. The beauty of these places resides more in the vertical cliffs and steep, wooded talus slopes than in the stream at the bottom of the Gorge.

In the Whirlpool Rapids and Lower Rapids conditions are somewhat different. Within the range of stage usually encountered these rapids are most beautiful at the lower stages. The beauty of these rapids is largely due to the huge rocks which break up the rushing waters into breakers, standing waves, and flying masses of spray and foam. At high stages these rocks are more deeply buried and do not produce these effects in anything like the same degree. Although the volume and velocity of the water is greater at high stages the beauty is less. That volume and velocity alone have little scenic value is well illustrated by the outfall of the Niagara Falls Power Co. tunnel. The volume of water entering the Maid-of-the-Mist Pool through this tunnel is nearly 10,000 cubic feet per second, or 10 per cent more than the usual discharge of the American Rapids and Falls. Its velocity is in the neighborhood of 40 miles per hour, much higher than exists in any of the rapids. Despite the immense quantity and velocity, the thing receives very little attention from visitors and is scarcely mentioned in printed accounts of the beauties of Niagara.

Photographs Nos. 107 and 108 show the upper end of the Whirlpool Rapids with discharges a little below and a little above the average, respectively. The low flow shows slightly larger breakers, although this is partly masked by the fact that No. 108 is a better photograph, being a shorter exposure in more brilliant light. Photograph No. 109 is the same place at high stage with a flow of 267,000 cubic feet per second. This was a long exposure on a very dark day, hence the general white and streaked effect of the moving water. Nevertheless, a close study will show that the spectacular effects have been largely reduced at the higher stage. This is especially marked in the case of the mass of foam directly in line with the center of the cantilever bridge. Photographs Nos. 110, 111, and 120 show another view of the Whirlpool Rapids under like conditions. Discounting the difference in lighting, it is evident that these rapids show to better advantage with a discharge of 203,000 than at a higher discharge. The large breakers just in line with the two ends of the bridge are markedly larger in photograph No. 110, although their details have been lost in the longer exposure.

In the Lower Rapids the same thing holds true. Photographs Nos. 115 and 116 show it a little. In photographs Nos. 117 to 119 the stage appears to make very little difference. No. 123 shows how much of the beauty is lost at a high stage, but reappears at the lower stages of Nos. 121 and 122. Photograph No. 127 shows the same when compared with 125 and 126. These pictures are somewhat deceptive, in that a very short exposure in brilliant light is required to give a good picture of waves and spray. In each case conditions were better in the pictures taken with 217,000 cubic feet per second

¹ See also supplementary report on p. 281.

than in those with 203,000. A careful study of individual waves will usually show that they are larger at the lower stage, and it must be borne in mind that the amount of spray and sparkle and the general effect upon the eye is commonly in proportion to the size of the wave. Of course, if the flow were reduced too far the rocks would not produce waves and spray, but would stand up bare with water running between them. In other words, there must be a point of maximum beauty in the rapids. If the flow be either increased or diminished from this point the beauty is decreased. It would appear from a careful study of these photographs and from frequent observation of these rapids under different conditions for many years that this point lies quite a bit below a flow of 200,000 cubic feet per second.

To sum up, it may be said that—

1. The American Rapids are not much affected by stage, but look best with a moderately large flow.
2. The Canadian Rapids are very little affected by stage, except the northwest corner, which require an extremely high stage to cover the shoal there.
3. The American Falls looks best at high stage.
4. The "notch" of the Horseshoe Falls is of small scenic value at any stage. At low stages it is more often visible, because there is then less mist.
5. The ends of the Horseshoe Falls look very poor at low stage and poor enough at the ordinary conditions now prevailing. At very high stages they are marvelously improved.
6. The Maid-of-the-Mist Pool and the Whirlpool derive their beauty primarily from the Gorge, not the river, and are not affected by change of stage.
7. The Whirlpool Rapids and Lower Rapids are at their best at a comparatively low stage. As the flow increases much of their attraction is lost.

*Recession of falls.*¹—It has been recognized by all students of Niagara Falls that the Falls are continually eroding their crest and thus receding up the river. It is quite evident that the Falls must once have been located at the edge of the escarpment at Lewiston and have gradually moved back to their present position, excavating the Gorge as they traveled. The time required for this journey is variously estimated by geologists, but the most authoritative values lie between thirty and forty thousand years.

The manner in which the recession takes place is well described in the following extract from folio No. 190 of the Geologic Atlas of the United States, published by the United States Geological Survey:

The brink of the Horseshoe Falls is formed by 80 feet of hard, massive dolomite (Lockport), beneath which is 60 feet of relatively soft shale (Rochester), extending down nearly to the level of the pool below. (See pl. No. 17.) A short distance above the water is another layer of hard limestone (Irondequoit), only 15 feet thick. Opposite the American Falls a thin layer of hard sandstone (Thorold) is exposed about 15 feet beneath this limestone. Then follows relatively soft shaly sandstone of the Albion formation for 50 or 60 feet below the surface of the pool, beneath which is another sandstone layer (Whirlpool sandstone), 25 feet thick. Beneath this in turn is 300 feet or more of soft red shale (Queenston), extending below the bottom of the pool. Thus a massive

¹ See also supplementary report on p. 281.

layer of hard compact limestone overlies several hundred feet of relatively soft shales containing a few thin layers of hard rock.

The resistance to stream erosion of the massive layer at the top is much greater than that of any of the layers beneath it. The thin, hard beds in the underlying shales are at a decided disadvantage in resisting the work of the cataract, for the water only glides over the massive top beds, but strikes with tremendous force on the thinner beds 150 to 200 feet below wherever they become exposed. Direct impact of the falling water on the rocks above the level of the pool is not the chief process in gorge making, however; in fact, it counts for very little. By far the most important factor is the scouring of the bottom and sides of the pool at the base of the Falls, where the mass of falling water strikes. The shale is gradually worn away by the impact of the water alone, but more efficient tools are continually supplied. By the wearing away of the soft shale the hard layers are undermined and blocks and fragments of limestone and sandstone fall into the pool, where the tremendous turbulence of the water spins them round and round after the manner of pestle stones in the making of potholes. (Pl. No. 17.) At first the blocks are angular, but even after they become rounded and although they are themselves worn away in the process, they wear the softer rock away more rapidly, hence the depth of the pool is greater than the height of the Falls.

Thus the brink of the cataract is always an overhanging ledge projecting beyond the face of the supporting rock wall. Whenever a block falls from the brink it contributes to the lengthening of the gorge at the top, and at the same time supplies a new tool for lengthening it at the bottom. With each fall of rock from the brink the supporting wall behind the Falls is attacked with renewed vigor and the lengthening of the gorge goes on for a time at a slightly faster rate. This process has resulted in the making of the whole Gorge from Lewiston to the Horseshoe Falls, except the basin of the Whirlpool, which is older than the rest of the Gorge.

More than a dozen surveys of the crest line of the Falls have been made during the last century and a half, and are available for determining the rate of recession of the Horseshoe Falls. Five of the most valuable of these are shown on plate No. 18.

The first is from a plane table survey of the Niagara River made under the direction of Capt. John Montresor, Royal Engineers, in 1764. The original map is in the British Museum. The crest line on plate No. 18 is taken from a reproduction of Montresor's crest line in *The Falls of Niagara*, published by the Canadian Department of Mines in 1907. This original map was on a small scale and shows minor inaccuracies of detail, nevertheless it is of great value in illustrating the recession of the Falls, as it is by far the oldest survey we possess.

The second line on the plate is from a map made by James Hall in 1842. This was the first careful trigonometric survey of the crest line made especially to establish a basis for measuring the recession of the Falls. This appears to have been careful and well-executed work. A series of stone monuments were left to which all subsequent surveys have been tied. This line was also taken from a reproduction in "*The Falls of Niagara*."

The next survey made was that of the United States Lake Survey in 1875. This was a good piece of work. The third line on plate No. 18 shows the crest line determined by this survey reproduced from the original manuscript map. During the next 30 years four or five surveys were made. These have not been reproduced as they would confuse the map with too many lines without adding materially to the information conveyed.

The fourth line shown represents another survey executed by the United States Lake Survey in 1906. This was also taken from the original manuscript map. The fifth line is a survey made for the

present investigation. The engineers who performed the field work were Lake Survey employees, and the method used and results obtained were strictly comparable with those of the earlier surveys of that organization. This survey was made in the fall of 1917.

While these last four lines show certain minor discrepancies, notably in the vicinity of the international boundary line, they give a very satisfactory record of the rate of recession of the Horseshoe Falls. The inconsistencies are chiefly between Hall's line of 1842 and the three lines surveyed under the direction of the corps of engineers. The latter agree very well among themselves. Montessoro's line was much less carefully surveyed, and not being referred to any permanent monuments or landmarks it is not so well located on the sheet. It may very likely be in error as much as 50 feet at any point, and possibly more than twice that amount in some places. Its early date, however, gives it great value, as it is the best basis we have for computing the rate of recession in earlier years.

The exact measure to be used in expressing the rate of recession is a thing somewhat different to determine. In preparing Table No. 26 the following method was used: A line, m-n, was drawn from the east end of Montessoro's crest line on Goat Island through the southwest corner of the Ontario Power Co.'s power house to the west edge of the Gorge. The length of this line, 1,200 feet, was taken as the ultimate width of the Gorge, which the Falls is excavating. This agrees with the width adopted by Spencer (Falls of Niagara, p. 28) based on two other measurements. Then the increase in the area bounded by this line and the crest line divided by 1,200 is the average amount by which the Gorge has been lengthened in any given time. Dividing this by the length of time in years gives the average rate of recession. The maximum recession between any two successive lines was formed by measuring the length of the longest line that could be drawn between them as nearly as possible perpendicular to each. The points selected for the ends of these lines are indicated on the map by the lower case letters a, b, c, etc. Dividing their lengths by the elapsed time gives the maximum rate of recession.

TABLE No. 26.—Rate of recession of Horseshoe Falls.

	Elapsed years.	Area of recession.	Mean rate of recession.	Mean recession.	Mean rate of recession.	Line of maximum recession.	Maximum recession.	Rate of maximum recession.
		<i>Square feet.</i>	<i>Square feet per year.</i>	<i>Feet.</i>	<i>Feet per year.</i>		<i>Feet.</i>	<i>Feet per year.</i>
From 1764 to 1842.....	78	330,000	4,870	317	4.1	a-b	470	6.0
From 1842 to 1875.....	33	202,000	6,120	169	5.1	c-d	160	4.8
From 1875 to 1906.....	31	124,000	4,000	103	3.3	e-f	180	5.8
From 1906 to 1917.....	11	53,000	4,820	44	4.0	g-h	75	6.8
Total from 1764 to 1917.....	153	759,000	4,960	633	4.1	a-k	775	5.1

This table indicates that for the last century and a half the apex of the horseshoe has been cutting back at an average rate of about 5 feet per year, while, if it be considered that the cataract is excavating a gorge 1,200 feet wide, the average progress was at the rate

of about 4 feet per year. As a matter of fact, it appears that the falls are now forming a gorge which will run to the southeast rather than southwest as before, and that this new gorge will be narrower than the old. The rate of recession in the new narrower gorge is faster than in the old, and the rate appears to be increasing in spite of the diversion of water for power development. The area excavated per year has not changed much, but in the narrower gorge it results in a greater lineal recession.

The result of this recession into a deep notch is a gradual concentration of flow into the center of the crest and a corresponding diminishing of the flow over the ends. The Lake Survey's gauge at the International Railway Co. intake indicates that the recession of the falls has reduced the depth at this point quite a bit since 1906. The amount of this lowering is difficult to determine, as the problem is complicated by a simultaneous lowering due to the increased diversion by the power companies. Unpublished reports of the Lake Survey state that the elevation at this gauge was reduced 1.78 feet between 1906 and 1912. Of this 0.38 was explained by the effect of increasing diversion and certain other artificial changes in the river, leaving 1.40 feet lowering due to the recession of the falls in six years. This appears to show that the depth of water at the ends of the crest line is being decreased by a greater concentration at the center.

There is no direct evidence of the reduction in the flow at the Goat Island end of the falls, although such a reduction has undoubtedly occurred. At the Canadian end, however, a real record is preserved. In 1875 there was a flow over the crest line as far north as the outfall of the Canadian Niagara Power Co.'s tunnel. As a result of the recession of the apex of the Horseshoe Falls the flow over this part of the crest became very thin and a great deal of bare rock was exposed. Soon after the Queen Victoria Niagara Falls Park Commission was appointed in 1887 they took measures to remedy this unsightly condition by filling in the land along this end of the crest and building a retaining wall. Ultimately about 415 feet of the crest has been walled up. The fact that this barring of the Canadian end of the Horseshoe Falls was due to natural causes and not to the diversion of the power companies should be emphasized, as the contrary statement has often been made. The work had been undertaken and more than one-third completed in 1895 when the total diversion for power did not exceed the inconsiderable amount of 2,000 cubic feet per second or 1 per cent of the river flow. It was completed before the second of the five large stations began using water. There can be no question whatever but that it was due to the recession of the falls and aggravated by the period of deficient rainfall which occurred about 1890. The building of the wall was not made necessary by the construction of the power plants and has been of no advantage to any of them.

As stated above, the result of the recession now occurring is to withdraw water from the ends of the Falls and concentrate it at the center. The ends are the parts that are conspicuously visible to spectators. The notch is quite invisible from the most frequented viewpoints and can not be seen to any advantage from any point. Thus the recession is causing a decided decrease in the beauty of the Horseshoe Falls. Also the greater concentration of the flow into the central notch causes

a thickening of the darkening curtain of mist and further obscures the spectacle. This effect is cumulative. Increased erosion in the notch causes concentration of flow there; concentration of the flow in the notch increases the erosion there. A vicious cycle is thus established which is tending to the rapid destruction of the Horseshoe Falls as we now know it. It may be confidently predicted that if nothing is done to check this process the not very distant future will see the whole Terrapin Point shelf left bare to a point several hundred feet south of where it crosses the boundary line and a similar though smaller effect on the Canadian side. A narrowed cataract not much more than a thousand feet in length will plunge into the end of a gorge correspondingly contracted; the whole will be shrouded in dense mist and bordered on each side by the dark and fissured bed of the present river. If the present rate of recession of the apex continues for a hundred years the International Railway Co.'s power plant would probably be left high and dry and the Canadian Niagara would be in serious difficulties. In four or five centuries the first cascade would be reached and the drying up of the American Falls would commence, two of the power houses would be shut down and all the others would be affected. Once the first cascade is crossed the formation of the rocks and channels is such that the lowering of the Chippewa-Grass Island Pool will be very rapid.

These evils may seem a long time in the future, but it must be remembered that they are based on a recession of the apex at the present rate of 6 feet per annum. The rate has been increasing for the past 40 years, and there is reason to believe that it will continue to increase as the flow becomes more and more concentrated. The recession has already done serious scenic damage at the Canadian end, also at Terrapin Point, and within a generation it may be expected that the visible damage at the latter point will be very great indeed.

The recession of the American Falls is a matter of very secondary importance and no new survey of the American crest line was attempted for this investigation. The conclusions to be shown from the best data available are well summarized in the following extract from the United States Geological Survey's Niagara Folio, page 23:

RECESSION OF THE AMERICAN FALLS.

Most of the surveys of the Falls have included a determination of the crest line of the American Falls, but in the survey of 1911 (by the United States Geological Survey) that determination was omitted, and the survey by the United States Lake Survey in 1906 is therefore the latest of that fall. Attempts have been made to compute its rate of recession, but with one exception the differences between the successive crest lines are so slight that it seems doubtful whether they are greater than the probable range of error. Indeed, the map on which the several lines are plotted seems to indicate errors of that magnitude in certain places where a later line projects farther out than an earlier one. Hall's map of 1842 shows a great salient at the north side of the American Falls that projects about 100 feet beyond the line shown by all the later surveys. Here, again, Mr. Gilbert made effective use of a camera lucia sketch which Basil Hall made of this fall in 1827, and showed conclusively that the large salient shown on Hall's map is an error.

Using the crest line of Hall's map, Spencer calculated the rate of recession to be 0.6 foot a year. After making the correction on Hall's map, Gilbert calculated that the rate was probably as small as 0.2 foot a year. But even that rate may be much too large. The deepest water passing over the American Falls is only 3.5 feet deep, and the average is less than 1.5 feet.

The crest line is nearly 1,000 feet long, and is an almost even continuation of the cliff line on either side of it. In fact, the deepest water on this fall passes over the ledge near Prospect Point, a part of which protrudes slightly beyond the general cliff line. The fall is nearly 168 feet high, but the water strikes upon great blocks and bowlders which rest, in part, upon limestone ledges of the Clinton formation. The blocks are simply the coarser materials of the talus. In all the time that it has existed—probably 600 to 800 years—the fall has not been able to remove the blocks or to make a measurable beginning of a gorge. It has removed the fine material of the talus and has probably steepened the base of the cliff somewhat, but has done little more. In short, it is doubtful whether the crest line of the American Falls has receded more than may be fairly ascribed to normal cliff recession due to weathering. If the slight reentrant in the central part of the crest line is due to recession produced by the fall, it must be a very old feature, for the water sheet is now thinner there than north of it. Moreover, the crest lines, as mapped by the several surveys, are more nearly in agreement in this reentrant than in most other places, and the reentrant is no greater than many others along the cliff where no side fall ever existed.

It would appear from this that the American Falls shares none of the suicidal tendencies of its larger neighbor and, as far as the operation of natural forces goes, it is destined to remain in practically its present condition for half a thousand years or so, when its waters will be drained away by the encroachment of the receding Horseshoe Falls upon the waters of the Chippawa-Grass Island Pool. The utmost change that it might experience would be the loss of the Luna Falls, due to the recession of the Main Falls beyond the head of Luna Island, and this might not have occurred in the time allowed.

Effect of present diversion.—The various power companies at Niagara are now diverting approximately 50,000 cubic feet per second around the Falls and into the Maid-of-the-Mist Pool. In addition, the New York State Barge Canal, the Welland Canal, and the Chicago Drainage Canal are taking some 12,000 or 13,000 cubic feet per second which would otherwise flow over the Falls and through the gorge. In the near future, when the New Welland Canal is put in operation and the plants now under construction at the Falls are finished, the total diversion affecting the Falls will be very nearly 70,000 cubic feet per second. Has the existing diversion of 62,000 from the Falls and 12,000 from the gorge done real and perceptible injury to the scenic beauty of the Falls and rapids? This question of the amount of damage that has resulted from existing diversions has been the center of much controversy, often generating more heat than light. It is worth while, therefore, to analyze the problem which it presents and expose some of the fallacies that have often been repeated.

The real crux of the difficulty lies in the fact that increase in diversion has been gradual and continuous, and the change in the appearance of the Falls has been correspondingly so. At the same time, large oscillating changes in the appearance are continually occurring, due to the varying stage of Lake Erie. Attempts to estimate the change by personal observation are therefore of little value. Even if the uninformed observer can make a successful mental comparison between what he sees to-day and his memory of what he saw 30 years ago, he is quite unable to tell how much of the change is the effect of diversions and how much is due to a difference in the stage of Lake Erie.

It frequently happens that some distinguished man whose pronouncements bear weight with the public visits Niagara and afterwards tells the reporters that he is certain that the Falls are to-day as great and glorious a spectacle as ever; he is distinctly impressed with the fact that they have not been diminished a particle since he first saw them when on his honeymoon in 1889. Or his statement may be that the vandalism of the power companies is ruining the Falls; he recalls clearly that in his boyhood days they were incomparably finer than at present. For the reasons given above these impressions are of no value whatever, nevertheless they are often seized upon and given wide publicity by those whose side in the controversy they favor.

The error which fluctuations in stage introduce into individual judgment of the scenic changes caused by the diversions tends to be usually in one direction; the change of stage diminishes the effect of the diversion more often than it exaggerates it. Diversion on a large scale began in 1895; the years immediately preceding this date are naturally selected as a basis of comparison with present conditions. Unfortunately the years from 1890 to 1895 are notable for having been years of very low water on all the lakes. The mean stage of Lake Erie for the year 1895 itself is the lowest recorded in 60 years. On the contrary, during the period from 1913 to 1918 the stage of Lake Erie has been unusually high, the year 1913 being the highest recorded since 1890. These high and low stages were due to various meteorological and other conditions entirely independent of anything occurring at Niagara Falls. As a result of these conditions a comparison of the appearance of the Falls before and after the diversions took place is very likely to be a comparison of the Falls with almost no diversion and a low stage of Lake Erie against the Falls with large diversions and a high stage of the lake. The effect of the higher stage is the opposite of the effect of the larger diversion and tends to conceal the latter.

Despite the difficulties it is quite possible to obtain ample and decisive evidence of the effect of diversions upon the beauty of the Falls. The very changes in stage which deprive ordinary observations of their value can be made the instrument of a very exact solution of the problem. The effect of changing the flow over the Falls by 50,000 cubic feet per second is much the same whether this change was due to the operation of power companies or to the oscillations of Lake Erie. If a man should view the Falls daily for two or three years, taking special note of conditions during heavy gales, he would see that the appearance varied widely from time to time. The highest stages that he saw would represent very fairly what conditions would be on average days if there had been no diversions and the difference between what he saw on average days and what he saw on the days of highest stage would be a pretty good measure of the effect of the diversion upon the scenic beauty of the Falls. Similarly, the difference in appearance on average days and on days of extremely low water would give him a measure of the same thing at lower stages.

By substituting the lens of the photographic camera for the eye of a human observer we are able to present a graphic and indisputable record of the facts. It is to be regretted that during the period of six weeks during which the photographer was prepared to take

these pictures, no very low stage occurred in weather which permitted photographs to be taken. However, a fairly satisfactory series at high and medium stages was obtained. These pictures are shown on photographs Nos. 74 to 127 and have already been described. Each picture showing the Falls or rapids above the Falls is marked with the approximate flow of water over the Falls in cubic feet per second. In these the effect of certain changes in discharge can be directly observed and the effect of other changes can be easily estimated.

In the American and Canadian Rapids above the Falls the pictures show the effects of a change of 85,000 cubic feet per second. These are noticeable, although not of great importance. The present diversions, of course, have an effect about three-quarters as great as this.

At the American Falls photographs Nos. 83 and 84 show the effect of a change of 65,000 approximately equal to the present total diversions, on the view from the Canadian side. Photographs Nos. 88 and 89 show views from Goat Island with a difference of 90,000. The better photographic conditions in the low-stage pictures tend to obscure the result, but a careful study will show real differences in favor of the high stage, particularly the greater depth of water and smoother curve over the crest.

The effect on the Horseshoe Falls is the most striking. This falls is shown from five different viewpoints in photographs Nos. 91 to 104, and in each the superiority of the pictures with the larger flows is incontestable. Nos. 98 and 99 show excellently the effect on the Goat Island end of the Horseshoe of a reduction of 65,000. This is a real measure of the results of the present diversions on this end of the falls. In the face of these photographs any contention that the beauty of the cataract has not been seriously affected becomes supremely ridiculous. Photographs Nos. 100 and 101, 103 and 104, especially the latter pair, show the result of slightly greater changes at the same place but taken from other viewpoints. Bear in mind that an effect equal to three-quarters of the difference between 103 and 104 has already taken place. Nos. 95 and 96 show the Canadian end of the Horseshoe with a flow of 165,000 and 225,000, respectively, a difference of 60,000 cubic feet per second. Again the proof of real damage already done is incontestable. No. 95 was taken at 3.20 p. m. November 7, 1917. If no water had ever been diverted from the Niagara River a picture taken on that day and hour would have been hardly distinguishable from photograph No. 96. These bare ledges of unsightly rock would have been covered with a flood of rushing water and the thin and broken streams trickling over the edge of the cliff would have given place to a leaping cataract but little inferior to that shown in photograph No. 96.

In the Maid-of-the-Mist Pool, the Gorge, and the Whirlpool the present diversion is only 12,000 cubic feet per second. A number of the photographs show the result of such diversions. On the whole the rapids make a finer showing with this water diverted than they did before. The difference, however, is very slight.

To sum up, the present diversions have done a slight amount of damage to the rapids above the falls and a somewhat greater amount to the American Falls. Both ends of the Horseshoe Falls have been

seriously injured and this injury will be increased by any further diversions. The diversions have had very little effect on the lower river and this mostly of a favorable nature. The damage that has been done should be repaired if possible and no further diversions should be permitted unless steps are taken to neutralize the damage that they will do.

Proposed remedial measures.—It has been shown that the scenic beauty of Niagara Falls has been appreciably damaged both by the recent recession of the apex of the Horseshoe Falls and by the diversion of water for power and for other purposes. The recession of the apex is progressing at an increasing rate and further power diversions are urgently desired and would be of great value to this country and to Canada. On the other hand the destructions or serious impairment of the beauty of this famous cataract will not be tolerated by the people of the United States and would provoke the expostulations of the whole civilized world. Under these conditions the question naturally arises, can not something be done which will repair the damage already done, prevent the self-destruction of the Horseshoe, and allow increased diversions without noticeable damage?

Such a possibility was seen as long ago as 1906 and was pointed out in a report to the Chief of Engineers in 1908, as follows:

* * * the damage already done, and that which may be anticipated from further diversions * * *, may be largely, if not entirely remedied by a submerged dam placed in the bed of the river immediately above the Horseshoe Falls. The dam, if properly planned, would serve to change the direction of flow, so as to increase the streams that feed the falls at Terrapin Point and at the Canadian shore. The decrease in the mighty volume that overflows the center or apex of the Horseshoe would not be noticeable. * * * A very direct result of the construction of this submerged dam would be a diminution in the rate of recession of the apex of the Horseshoe. This in itself is extremely desirable. (S. Doc. No. 105, 62d Cong. 1st sess. p. 15.)

The underlying principle of the design of such works is pointed out by the fact that while the American Falls carries but one-sixteenth of the flow over the Falls, it probably furnishes one-half of the spectacle. The American Falls is easily approached from either end and from below and a fine view of its full face is obtained from the opposite side of the Gorge. On the other hand, the approachable ends of the Horseshoe are greatly inferior to the American Falls, while the great fall of water into the notch can not be observed from any point. As matters now stand, there flows over the central 600 feet of the Horseshoe Falls a volume of approximately 80,000 cubic feet per second, which not only is entirely wasted in that it creates neither scenery nor power but which is actually a detriment in that it is the cause of the destructive erosion described above.

Photographs Nos. 72 and 73 are pictures taken with the intent of showing the whole Falls at their best. Note in each instance the marked superiority of the American Falls. The cloud of mist which shuts out so much of the Horseshoe is a feature which is always present.

The average flow over the American Falls is about 9 cubic feet per second over each linear foot of crest. This produces a waterfall whose beauty and grandeur is admittedly unsurpassed. Over the Horseshoe the average flow per foot is about 57 cubic feet per second over each linear foot of crest, or more than six times as much as the

American, but it is unevenly distributed. The whole eastern end of the crest, out as far as a point 200 feet beyond where the crest crosses the international boundary, has a mean flow of 4 cubic feet per foot, or less than half as much as the American Falls; in much of the length the intensity of flow is much less than this. While the most conspicuous part of the crest has this meager flow, in the apex of the notch, hidden from view by walls of rock and curtains of water and mist, there is a flow of perhaps 200 cubic feet per second over each foot of crest, or twenty-two times as much as at the American Falls.

If 125,000 cubic feet per second out of the 150,000 usually flowing over the Horseshoe Falls were diverted for power development, and the remaining 25,000 were distributed uniformly over the 2,600 feet of crest line the whole length of the Horseshoe would have an appearance similar to that which the American Falls now has. The cloud of mist would be greatly reduced and much more of the Horseshoe would be visible. A glance at photographs Nos. 72 and 73 will show how much the effect of the whole would be enhanced. At the same time, the recession of the Falls would be very greatly reduced. Ultimately the rate of recession would not be much greater than that of the American Falls.

For various reasons so great a diversion as 125,000 is neither possible nor desirable, but by action along the lines indicated it will be possible to increase the beauty of the Horseshoe Falls, reduce the cloud of mist, check the recession which is now destroying the Falls, and develop much more power than is now generated. At the same time the flow over the American Falls could be somewhat increased and conditions there restored to what they were in 1890. The questions of the allowable diversion and of the design of the remedial works are taken up in subsequent sections of this report.

2. ALLOWABLE DIVERSIONS AROUND THE FALLS.

Flow required for sluicing ice.—In the winter and early spring large amounts of ice come down the Niagara River and go over the Falls. It is essential that any scheme shall maintain a sufficient flow over the Falls to carry this ice and prevent the formation of ice jams in the rapids above the Falls. Such ice jams might cause serious damage by floods and by cutting off the water supply to some of the power houses. A consideration of ice conditions at the American Falls will indicate how much water is needed for this purpose.

On one or two occasions, notably in February, 1909, the American channel has been blocked by ice. This has occurred only on days of extremely low flow. At ordinary stages the American channel has always been able to carry away its share of the ice, even in the record-breaking winter of 1917-18. The ordinary flow may be taken at 9,000 cubic feet per second, although during many severe winters the channel has been kept open by a smaller average flow than this. The crest line of the Falls is about 1,000 feet long and the width of the channel in its widest and shallowest part is about the same if the width of the islands be deducted. That is to say, a flow of 9 cubic feet per second for each foot of width has always been sufficient to keep this channel open. Allowing the same proportion to the 3,300-foot Canadian channel would give a flow of 30,000 cubic feet per

second needed to keep this channel open. Of course, conditions are not the same in the two channels. It would seem that in the American channel with so many islands they would be more severe. However, to be decidedly on the safe side, we will increase the amount by half and assume that a minimum daily mean flow of 45,000 cubic feet per second must be retained in the Canadian channel for sluicing ice.

The American Falls has been little affected by the existing diversions. Making the best possible use of the scanty observations available it appears that its mean flow under natural conditions was about 11,000 cubic feet per second. The present power diversions have reduced this to about 9,000 cubic feet. The effect of this reduction upon the appearance of the Falls has been but slight. With a diversion of 80,000 cubic feet per second, however, unless some remedial action is taken, the flow would probably be reduced to 4,000 or 5,000 cubic feet per second, which would ruin both the Falls and the rapids above it. It will not be a difficult matter to deepen the channel leading from Port Day to the first cascade of the American rapids and restore a flow of 11,000 or 12,000 cubic feet in spite of the great diversion. The flow at the lowest daily mean stage would be about 4,500 cubic feet. This is at least as great as the lowest daily mean flow of the past, and conditions of ice sluicing would be as well satisfied as they are now.

Minimum flow of river.—The lowest daily mean flow recorded since the installation of the Buffalo gauge was 138,000 cubic feet per second, which occurred on February 1, 1915. The next lowest was 148,000 on March 19, 1901. The flow was 160,000 or less on 15 days. One of these was in April, two were in March, and all the rest were in January, February, or December. On each day there was a moderate to high easterly or northwesterly wind and commonly rain or snow was falling. In other words, these low stages occur on days when sight-seeing is a disagreeable task and usually at a time of year when the various beautiful ice effects at the Falls do a great deal to afford a sort of scenic compensation for a temporary reduction in the flow over the crest.

The extreme minimum flows are due to the effects of easterly gales on Lake Erie. These extreme low stages of the Buffalo gauge last but a few minutes and do not produce their full effect in diminishing the flow over the Falls. The minimum stage recorded by the Buffalo gauge was 567.88, on February 1, 1915, at 6.54 p. m. If the discharge formula be applied to this reading, it gives a value of $Q=106,000$ cubic feet per second. The actual flow probably never fell below 110,000 or 115,000 cubic feet per second.

On the day when these minimum flows occurred the total diversion by the Erie, Welland, and Chicago Canals probably did not fall as much as 5,000 cubic feet per second below the amount now being taken at these places. Allowing for a possible increase in the diversions the following assumptions will be made for use in deciding on future limits of diversion:

1. The scenic beauties of the falls must be properly maintained when the total river flow is reduced to 150,000 cubic feet per second. The daily mean flow will be less than this on a few very rare occasions, but these will usually be on days of bad weather in the winter months.

2. The ice-sluicing powers of the cataract must be preserved when the total river flow is reduced to a daily mean of 130,000 cubic feet per second.

3. Rare and brief reductions of flow may occur down to as little as 100,000 cubic feet per second. These will last but a few hours and need not be much regarded. If they should threaten to cause any serious trouble, it should be possible to shut off part of the power diversion for a few hours.

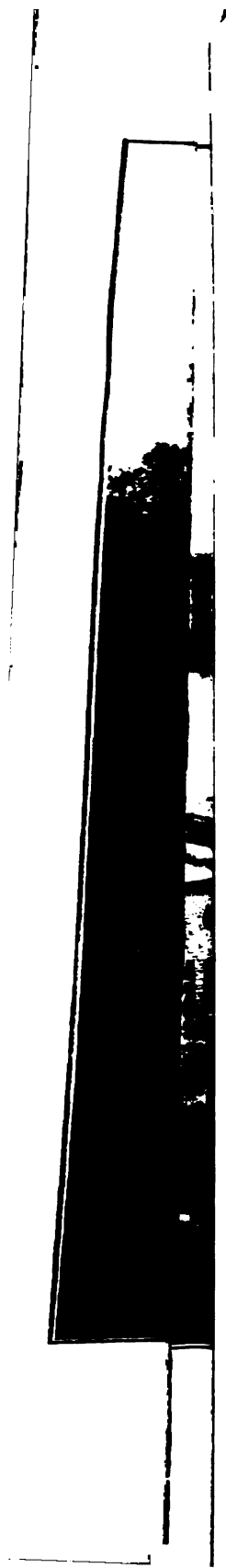
Permissible diversions.—The minimum requirement for ice sluicing adopted above was 45,000 cubic feet per second for the Horseshoe Falls and 4,500 for the American, a total, in round numbers, of 50,000 cubic feet per second; 130,000 cubic feet per second has been adopted as the lowest probable daily mean flow for which full ice-sluicing capacity must be maintained. The difference between these two quantities, or 80,000 cubic feet per second, is the amount which may be diverted. Permits for diverting water in excess of that now being used should contain a clause authorizing the Government's representatives at the Falls to order an immediate reduction of load by 70 per cent for a period not to exceed six consecutive hours whenever the condition of the river makes it advisable, but not oftener than four times per year. Such a clause, if the powers it confers be intelligently handled, would prevent any trouble from temporary extreme low water. It probably would not be necessary to use these powers except at intervals of several years.

It must be thoroughly understood that the allowing of any such diversion as 80,000 cubic feet per second is absolutely contingent upon the construction of remedial works.

Use of extra water available at higher stages.—If remedial works are constructed and 80,000 cubic feet per second are diverted the appearance of the Falls will be satisfactory on the days of minimum flow; that is, days when the mean flow of the river is 130,000 cubic feet per second. The gauge records show that on 997 days out of every 1,000 the mean flow exceeds 160,000 cubic feet per second, and days when the flow is reduced to 180,000 are rare. On the other hand, flows as great as 230,000 or 240,000 cubic feet per second are not uncommon, and flows in excess of 300,000 have been recorded. After the remedial works are built and the 80,000 cubic feet per second diverted, the excess of river flow above 180,000 cubic feet per second contributes little or nothing to the scenic beauty of the Falls while it adds materially to the destructive erosion.

In view of these facts it appears that further diversion for power development may be permissible under certain limitations. After the full amount of 80,000 cubic feet per second has been used and marketed, if careful observation indicates that no harmful results will follow, plants might be installed to divert the excess above 180,000 cubic feet per second of total river discharge. These plants would be subject to occasional shutdowns due to low stage, and would have to be provided with a steam station to serve as a "stand-by," or else develop industries in which occasional shutdowns could be tolerated. These are handicaps to which the majority of existing hydraulic plants in this country are subject.

Final result.—When these diversions have been made and the remedial works constructed, the American Rapids and Falls will be restored to a condition comparable to that of 1890, or even a little

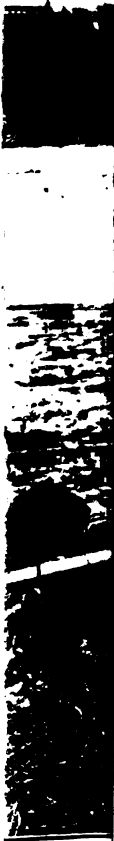




Photograph No. 131 (10.25 a. m., Apr. 22, 1920).—AMERICAN RAPIDS ABOVE GOAT ISLAND BRIDGE.
River discharge 185,000 cubic feet per second. Flow over Falls 140,000 cubic feet per second. Compare
Photographs Nos. 74-77 in report dated August 30, 1919.



Photograph No. 134 (2.30 p.m. April 22, 1920) - AMERICAN FALLS FROM GOAT ISLAND.
River discharge 175,000 cubic feet per second. Flow over falls 125,000 cubic feet per second. Complete
Photograph No. 135 (2.30 p.m. April 22, 1920) - AMERICAN FALLS FROM GOAT ISLAND.



GOAT ISL
aphs Nos. 9



Photograph No. 136 (12.45 p. m., Apr. 22, 1920).—WEST END OF HORSESHOE FALLS FROM CANADIAN SIDE.

River discharge 180,000 cubic feet per second. Flow over Falls 135,000 cubic feet per second. Compare Photographs Nos. 95 and 96 in report dated August 30, 1919.



Photograph No. 137 (11.50 a. m., Apr. 22, 1920).—EAST END OF HORSESHOE FALLS FROM "THE REFECTORY."
River discharge 180,000 cubic feet per second. Flow over Falls 135,000 cubic feet per second. Compare Photographs Nos. 97 '99 in report dated August 30, 1919.



Photograph No. 138 (11.00 a. m., Apr. 22, 1920).—EAST END OF HORSESHOE FALLS FROM GOAT ISLAND.
River discharge 185,000 cubic feet per second. Flow over Falls 135,000 cubic feet per second. Compare Photographs
Nos. 102-104 in report dated August 30, 1919.



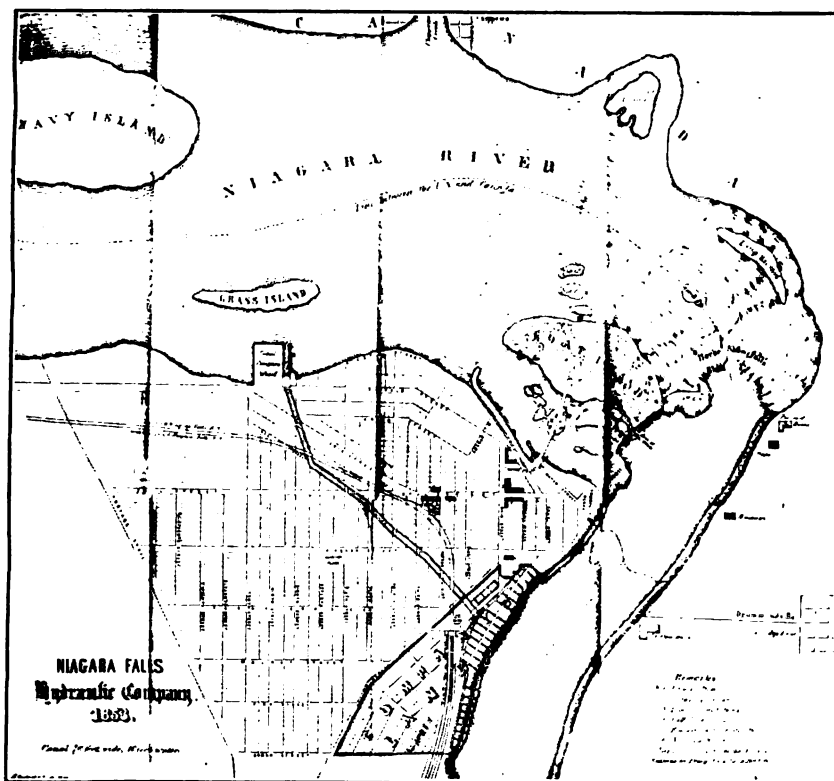
Photograph No. 139.—VIEW FROM GOAT ISLAND.

Looking toward the American shore before the establishment of the Niagara Reservation, July 15, 1885, showing paper mill on Bath, now Green Island.



Photograph No. 139.—VIEW FROM SAME VANTAGE POINT ON GOAT ISLAND.

Showing conditions as they are to-day.



Photograph No. 140.—MAP OF NIAGARA FALLS, N. Y., IN 1853.
Showing proposed Hydraulic Canal.



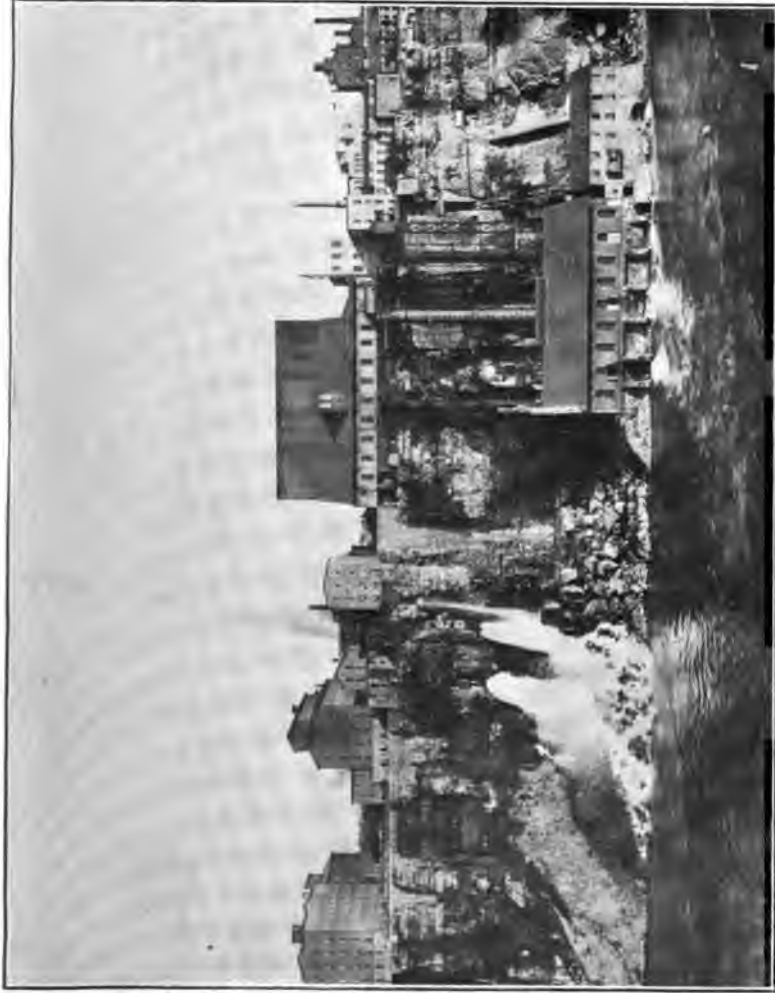
Photograph No. 141.- FOREBAY OF STATION 2, UNDER CONSTRUCTION. HYDRAULIC POWER CO.



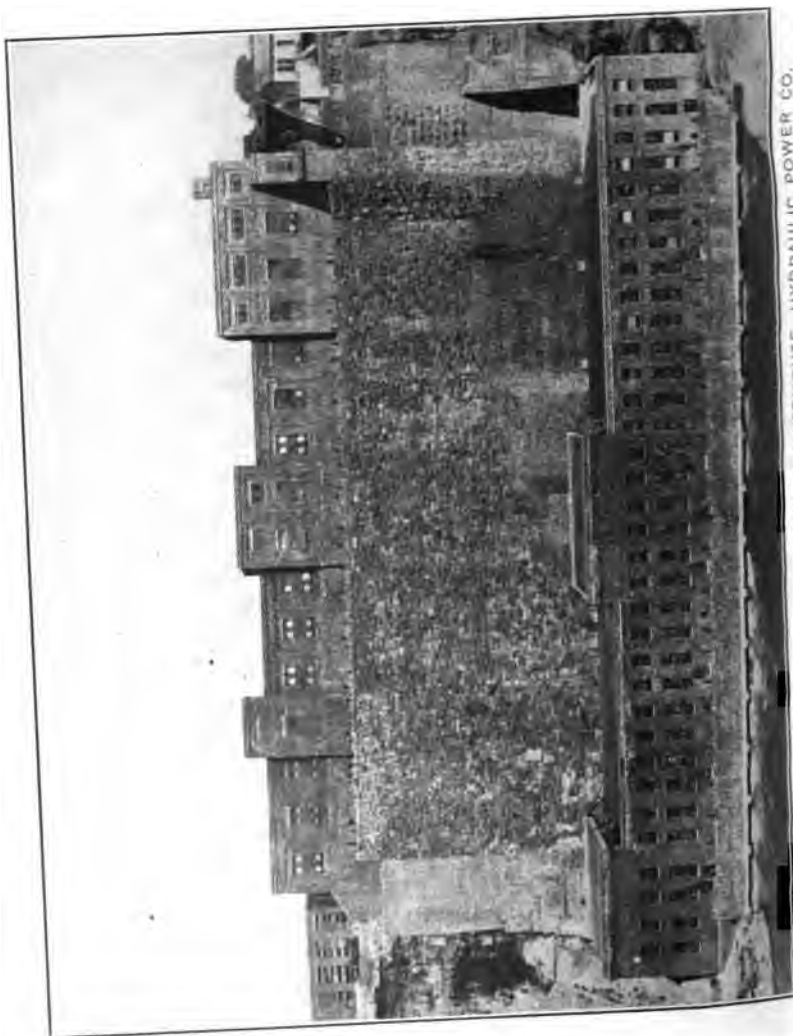
Photograph No. 142.—STATION 2, UNDER CONSTRUCTION. HYDRAULIC POWER CO.



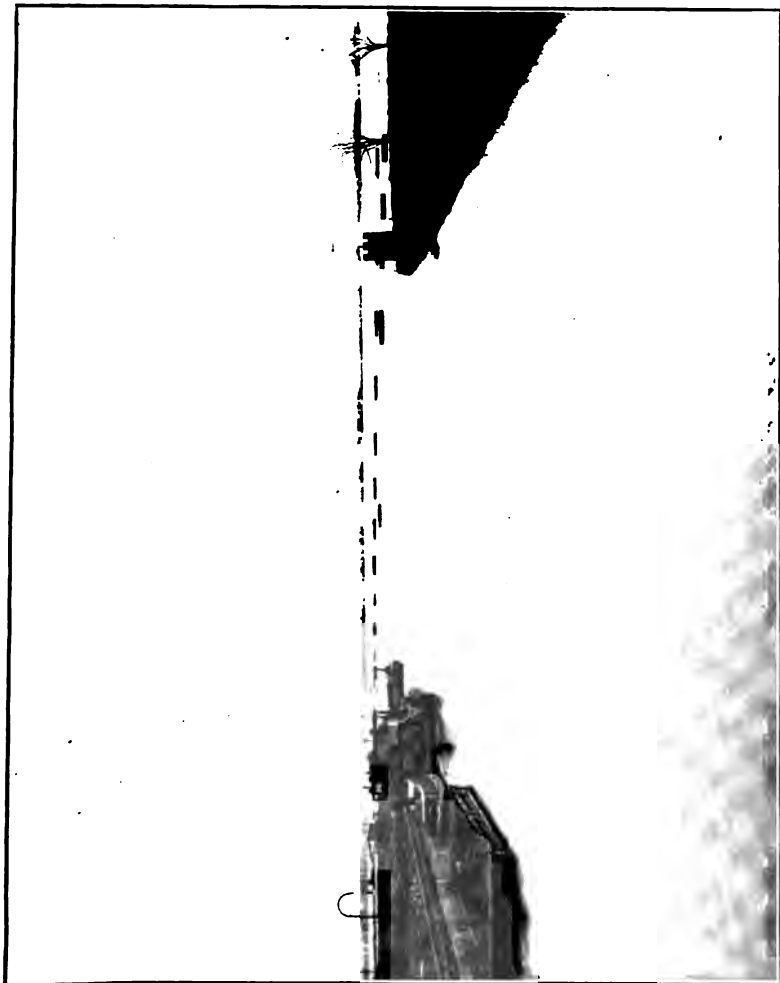
Photograph No. 143.—STATION 2 OF HYDRAULIC POWER CO.
Roof crushed by falling ice, January, 1904.



Photograph No. 144.—STATION 2 OF HYDRAULIC POWER CO. AND WATER WASTED BY PETTEBONE-CATARACT PAPER CO.



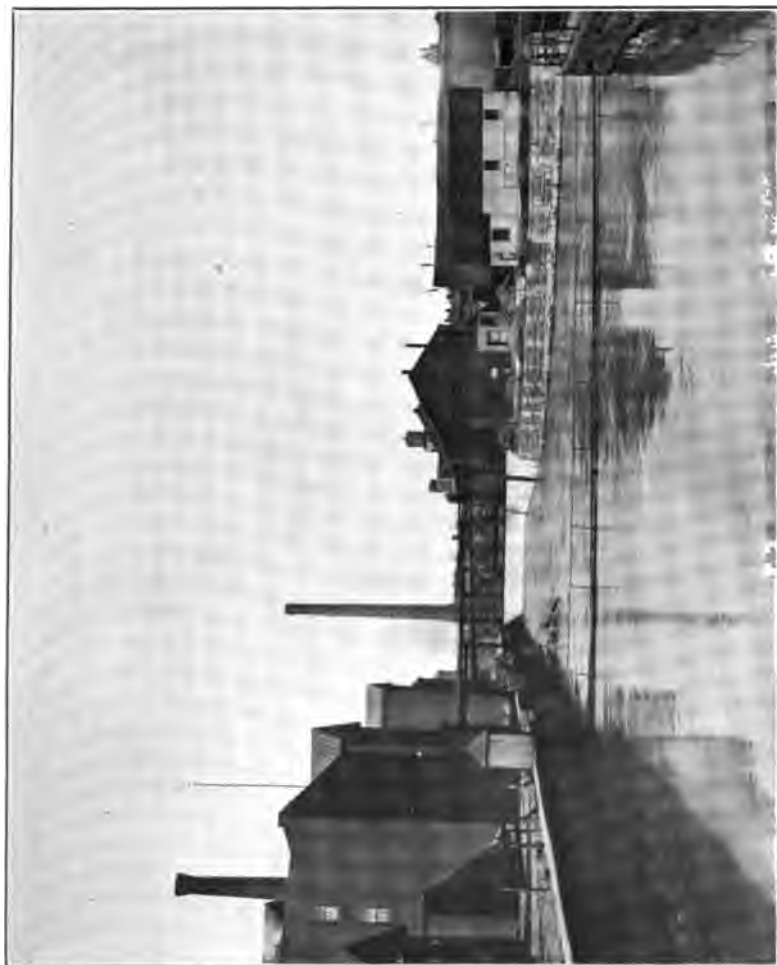
Photograph No. 145. -STATION 3 AND FOREBAY GATEHOUSE, HYDRAULIC POWER CO.



Photograph No. 146.—HEAD OF HYDRAULIC CANAL, PORT DAY, HYDRAULIC POWER CO.



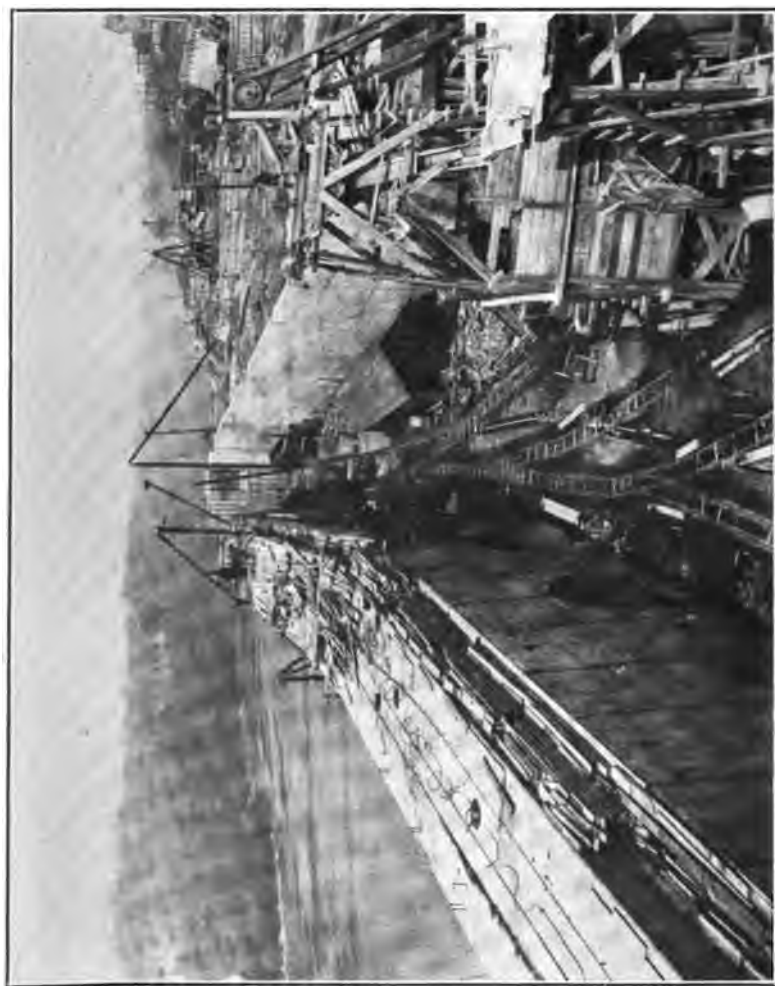
Photograph No. 147.—HYDRAULIC CANAL, ABOVE THIRD STREET. HYDRAULIC POWER CO.



Photograph No. 148.--BASIN AND FOOT OF HYDRAULIC CANAL. HYDRAULIC POWER CO.



Photograph No. 149. END OF BASIN AND GATEHOUSE OF STATION 3. HYDRAULIC POWER CO.



Photograph No. 150. --STATION 3, FOREBAY, UNDER CONSTRUCTION. HYDRAULIC POWER CO.



Photograph No. 151 STATION 3. FOREBAY. HYDRAULIC POWER CO.

better, both at mean stage and at low water. The upper part of the Horseshoe Rapids will be considerably damaged by the exposure of bare spots, especially at low stage. It is quite possible that the layer of these might be transformed into wooded islands, such as are now an attractive feature of the American Rapids. Also, at the low stage caused by these diversions, new cascades and breakers will probably be formed at points where the water is now fairly smooth. The lower part of the Horseshoe Rapids will be improved by having a greater depth on the shoals in the northwest corner and above Terrapin Point and by the creation of a new cascade on a grand scale at the site of the submerged dam.

The beauty of the Horseshoe Falls, which has been injured by the power diversions and by the recession of the Falls, will be restored and added to until the Falls takes on an aspect far more grand than it has ever had before. At mean stage its discharge will be from 40 to 45 cubic feet per second over each lineal foot of crest, or more than five times as much as the American Falls now has. This condition will obtain along the whole crest of the Falls, including Terrapin Point and the Canadian end. Each of these places will become a new and glorified "Prospect Point," with a great cataract leaping from the cliff at the spectators' very feet, but with five times the intensity of the Falls at Prospect Point. The long salient crest line near Terrapin Point, which the geologists call the "Goat Island Shelf," will be the site of Falls as accessible and conspicuous as the American Falls and five times as voluminous, while the now invisible sides of the notch will have similar falls, and they will be visible much of the time because the mist formation will be greatly reduced. The suicidal recession of the Horseshoe Falls will be checked and reduced to perhaps a tenth of its former value.

On days of ordinary low flow the discharge of the Horseshoe Falls per foot of crest will be about 30 cubic feet per second. This will give the ends of the Falls on days when their natural appearance would, without these works, be much worse than is shown on photographs Nos. 91, 95, and 97, an intensity of flow three times as great as the American Falls usually has.

The net result would be that while some minor damage would be done to the Horseshoe Rapids, the Falls, taken as a whole, would be vastly improved, the suicidal recession of the Horseshoe would be checked, and the amount of valuable electric power available would be greatly increased.

3. REMEDIAL WORKS.

Introduction.—The rapids above the Horseshoe Falls are so wide, their volume of flow is so large, and the velocity of the water is so great that at first glance the idea of building a dam or other works in the middle of them seems impossible and absurd. After careful study, however, it is found that the difficulties are not as great as they appear. Over a very large part of their area the rapids are comparatively shallow, and in many places the velocities are no greater than those with which the builders of the headworkers of the Ontario Power Co. and Toronto Power Co. have successfully contended.

In 1917 a survey of these rapids was made in connection with the present investigation, as already described in Section D. The results are shown in plates Nos. 19 and 22. Plate No. 19 shows the directions of the current in different parts of the rapids, while plate No. 20 shows the velocities. Plate No. 21 shows the depth of water at the time of the survey and plate No. 22 gives the elevations of the bottom above sea level. The contours on this plate are drawn to a vertical interval of 5 feet. The mean discharge of the Niagara River on the days of the survey was about 216,000 cubic feet per second, or about 5 per cent more than the general mean. The data in the American Rapids and east of Goat Island on some of these plates is taken from the work of the United States Lake Survey in 1907 and 1908.

As to the accuracy of these maps it may be said that plates Nos. 19 and 20 are very good. Plate No. 21 is fair. Plate No. 22 is by no means as accurate as the others. The elevations shown on it are based upon a series of assumptions as to the probable elevation of the water surface between the few observed points, and some of the assumptions had to be made with very little real evidence as a guide. As plate No. 19 shows, there are four areas of considerable size through which no floats passed.

These drawings are ample for giving a general idea of the conditions involved and for making a tentative design and estimate of proposed works for spreading the water from the center to the sides of the Horseshoe Falls. Before the final plans are made the power diversions should be increased to the full amount contemplated, so as to reduce the depths and velocities while work on the remedial works is in progress. While the diversion is being increased to this point automatic water gauges should be maintained at the six points where there have been gauges in the past, and possibly in one or two new places. When the diversion is complete more extensive surveys should be made. The extremely low stage which will then exist in the rapids will enable a much greater degree of accuracy to be obtained. From the results of this survey hydraulic models could be made. The final plans based on the gauge data and later survey should be carefully tested on the models before being adopted.

Conditions governing the design.—A study of the maps brought out the following features, all of which have had a considerable influence on the project presented: The center of the crest lies in a sort of cup into which the rock surface dips from east, west, and south. The depth of this hollow was not determined but its lowest point is well below elevation 500 and probably below 490. The ends of the crest line for 500 feet on the Canadian end and nearly twice as far on the Goat Island end are higher, with elevations ranging from 500 to 506. Upstream from the crest at the Goat Island end is a shoal with depths of from 1 to 4 feet extending several hundred feet from the island. At the Canadian end the water near the shore is deeper, but at a distance of about 300 feet from shore there is a very shallow spot, much of which is uncovered at very low stages.

As the result of these conditions the water converges into the central portion of the crest as is shown very clearly in plate No. 19. To show the distribution of velocities and other hydraulic conditions along the crest line, and for a hundred feet upstream, the data given on plate No. 23 was assembled. A section was taken across the four maps from Station W to Station D. The central part of this

section followed the curve finally adopted for the center line of the remedial weir; the ends are straight lines. This section was divided into 11 panels of approximately equal width, numbered from west to east. Through the panel points lines were drawn parallel to the current lines of plate No. 19, and it was assumed that the quantity of water crossing the section in any panel continued to flow between the lines from the ends of that panel until it reached the crest. In this way the distribution of flow upon the crest line was approximately determined.

The bottom and water surface profiles and the transverse velocity curve were scaled from the maps, also the angle that the current lines made with the section. From this data the discharge through each panel was completed. The sum of the 11 panel discharges as thus computed is 167,800 cubic feet per second. Computing the river flow from the mean elevation of the Buffalo gauge and subtracting the estimated diversions, and flow over the American Falls, gives a value of 157,000 cubic feet per second, a difference of only 7 per cent. This is an excellent check on the general accuracy of the float survey.

The panel discharges were corrected in the ratio of 167,800 to 157,000 and then divided by the length of crest line that each one serves. This gives the discharge per foot of crest at different points. As plate No. 23 shows, more than half of the total flow passes through panels 7, 8, and 9, and flows over the falls on a crest line only 420 feet long or one-sixth of the total crest line.

When the power diversion has been increased to 80,000 cubic feet per second and the proposed remedial works are finished the total flow over this fall will be reduced from 157,000 to 115,000 and will be distributed more uniformly over the crest, the ideal being a uniform flow of 44 cubic feet per second over each foot of crest line.

In designing the weir it must be kept in mind that part of this work must be done in depths as great as 12 or 14 feet and velocities as high as 20 or 22 feet per second. The bottom is known to be very irregular. When part of it was unwatered by the Toronto Power Co.'s cofferdam it was found to consist of solid rock carved by the water into great blocks separated by cracks often a foot wide and several feet deep. Under the existing conditions it will be difficult to do much to level the bottom under any proposed construction and the design should be such that very little preliminary leveling is needed.

Another necessary feature of the design is introduced by the uncertainty as to the exact height to which the weir must be built at different points. The hydraulic problem involved is so complex that the exact height required to produce the desired effect can not be computed. An approximate estimate can be made, but the height finally adopted must be determined by experiment.

The general scheme adopted was that the high Canadian end of the Falls and the shoal south of it should be cut down by excavation in the cofferdam; that the high places near Terrapin Point and to the south should be similarly excavated in another cofferdam; that a submerged weir, curved in plan, should be built across the central part of the rapids a short distance upstream from the "notch" of the Horseshoe Falls; and that the American channel should be given

a flow of 12,000 cubic feet per second by means of a submerged compensating dike extending from Goat Island to Chippewa.

Location.—As stated above, the final location of the weir and of the excavations at the ends of the Falls can only be determined after the diversions have been made, and the result of new surveys and model tests have been studied. The recession of the crest line may change conditions decidedly between now and the time when work is actually started. In order to get an approximation of the cost of the works, however, a location was made as of present date. A small model of the rapids in relief was constructed from data on plates Nos. 21 and 22 and carefully studied. Two preliminary locations were worked up in considerable detail and finally rejected. The ideas finally adopted are shown on plate No. 26.

The center line of the weir as located is an arc of a circle of 540-foot radius; the length is 1,380 feet. The depths and velocities now existing at the site of the weir are shown on plate No. 23, where the weir covers panels 3 to 9, inclusive. Several points had an influence in determining this location. Because of the "cupping" of the river bottom around the apex of the crest the structure must be close to the crest; otherwise after the water has been spread out to the ends it would be again concentrated in the center by the slope of the rock. The "cupping" also has weight in determining the adoption of the curved, rather than the straight form. The curved form is also made necessary by the requirement that the ends of the weir shall make such an angle with the current as to deflect it away from, not toward, the center. Aesthetically, the curved plan is much more desirable.

The height of the weir at various points can not be computed by hydraulic formulæ, as the problem is much too complex for analytical treatment until much more complete data are available. Before construction starts a preliminary profile should be adopted, based on experiments with large models.

In locating the end excavation the first thing considered was the shoal near the west end of the weir. It was obvious that this should be removed except that a little of its downstream edge might be left to serve as an extension of the weir. It was decided to excavate the area marked "L" on Plate No. 26 down to elevation 510. At the west end of the crest line the area marked "GFKH" is to be excavated, the bottom sloping from elevation 505 along the line GH to 501 at K and 498 at F. This would serve to give a good depth of water at the extreme end of the Falls even at low stages.

At the east end it was determined to cut two channels leading from behind the weir to the crest line along the "Goat Island Shelf." These are marked "NMRO" and "OSTP" on plate No. 26. The strip of rock left behind them will form a sort of irregular cascade over which some water may flow from one channel to the other at high and medium stages. Its purpose is to give a more uniform distribution of flow on this end of the crest. The bottom of the upper channel slopes from elevation 507 at OP to 503 at RQ and is level at this elevation between there and the crest. The bottom of the lower channel slopes from elevation 508 at NO to 506 at M and 503 at R. The crest line along here is not touched.

Of course, these channels are not given a smooth finish, but are purposely left rough to give a natural appearance to the rapids flowing over them. Steps and other obstructions might be left in them.

It would be desirable if the channels on the east side extended farther south at their upstream end. The reason that they are not so shown is that just south of NO the swiftest currents in the whole rapids are found and it was thought undesirable to extend the cofferdam any further in this direction. If it is found possible, without undue expense, to build this cofferdam farther south than the position shown on the map, it would be well to extend these channels.

Plate No. 27 shows bottom and water surface profiles, transverse velocity curve and other hydraulic data at mean stage after the construction of the proposed works. The section is from Station W to the weir, along the weir, and then to Station D. This is the same section as is shown in plate No. 23, and plates Nos. 23 and 27 should be compared to show the results of the proposed works. This plate makes no pretensions to accuracy but is based on the best data and engineering judgment available. The required height of the weir at each point and the height to which the water will rise behind it can only be determined by trial. The high point in the water surface profile near panel 8 is due to the very high velocity which will still exist upstream from this point, which, being checked by the weir, raises the elevation of the water surface according to the well-known pitot tube law. The smaller rise in panels 3 and 4 is due to a similar cause. Of course, no such perfect uniformity of flow over the crest of the Falls as this plate shows can be obtained. The data on the plate gives the ideal results desired; in practice they can be but approximately realized.

Work in the American Channel.—Before the power diversions began the mean flow in the American Channel was a little more than 11,000 cubic feet per second. The present diversions have reduced this to about 9,000 with a very slight diminution of the beauty of the American Falls. If the diversion be increased to 80,000 cubic feet per second, and this all diverted above the first cascade, the flow in this channel will be reduced to but little more than 4,000 cubic feet per second, unless some remedy be provided. With a mean flow as small as this, the appearance of the Falls would be very greatly damaged, at mean stage and at low stage the Falls would be nearly dry.

In Section G-3 of this report is outlined a plan for compensating the levels of the Niagara River for the lowering caused by the power diversions and other diversions of the water of the Great Lakes. This plan consists of dumping the excavated rock obtained in the construction of the new power plants in such a way that it will serve as a submerged weir to raise the level of the Chippawa-Grass Island Pool. This would form a convenient and not unduly expensive method of disposing of this waste rock and it is understood that the power companies are ready to do it without expense to the Government. In fact two companies are now placing spoil in the desired location and considerable compensating effect has already been obtained.

The dumping of a sufficient quantity of spoil in the river below the line from Port Day to Hog Island will restore the Chippawa-Grass Island Pool to the elevation which it had before diversion of water from the Great Lakes commenced. The spoil should be dumped chiefly in the deeper parts of the river so that no shoals will be formed which might be obstructions to the free passage of

ice and drift. To maintain the full discharge of the American Falls no rock should be dumped within 1,500 feet of Port Day. From the northern end of this spoil bank a similar obstruction should extend westward to the head of Goat Island. This will prevent too much water sweeping around the American end of the weir and then turning south into the Horseshoe channel again. This part of the work lies in shallow water of moderate velocity, where the spoil can be easily placed from a trestle or cableway. For the other part, in deeper water, dumping from scows is now being employed.

The exact quantity of material which must be placed to produce the effect required can not be figured in advance. If the work of depositing it proceeds systematically with careful comparison of the gages at Buffalo, Chippawa, Port Day, and Wing Dam the desired condition can be produced. The flow over the American Falls should be made 12,000 cubic feet per second at mean stage. This is slightly greater than its natural flow and ensures a satisfactory spectacle at all seasons and all ordinary stages.

4. ALLOWABLE DIVERSION AROUND THE RAPIDS.

Problem somewhat different from that in Section E-2.—The question of the permissible diversion around the Whirlpool Rapids and Lower Rapids rests on a somewhat different basis than the question of diversion around the Falls. The photographs give no information about extreme low stages and there is nothing to afford a measure of the quantity required for ice sluicing, as the American Falls did in the other problem. All the available records of soundings and velocities in the Gorge have been collected, compared, and carefully studied. The records of gauges maintained on the lower river by the United States Lake Survey and by the Hydraulic Power Co. were studied and other gauges were installed and maintained during this investigation. Some of the engineers employed had been students of the hydraulic conditions of the Niagara River for years, and no endeavor was spared to observe the rapids under unusual conditions and to discuss them with others who had done so.

Limiting conditions.—The mean and extreme conditions to be provided for here are the same as on the upper river; that is—

1. Scenic beauty must be protected down to minimum flows of 150,000 cubic feet per second.
2. Ice-sluicing capacity must be protected down to 130,000 cubic feet per second of daily mean flow, and
3. Down to 100,000 cubic feet per second for temporary extreme stages of only a few hours' duration.

The scenic requirements are that in general there shall be no noticeably shoal spots of any size. A few isolated boulders against which the waters dash are not objectionable. The volume and velocity of the stream must be such that its impact upon the submerged rocks breaks it up into spray, breakers, standing waves, and white water. A moderate reduction of flow will certainly increase these features, as they are now noticeably more conspicuous at low stages than at high.

The steeper portions of the rapids seem able to take care of all their ice difficulties with little trouble. The most critical point is at

the head of the Whirlpool Rapids near the railroad bridges. The annual ice bridge that forms in the Maid-of-the-Mist Pool above the upper highway bridge sometimes breaks loose and comes down stream in large masses. These jam into the narrowing gorge at this point and the river must be left with sufficient power to break up these masses and carry them down into the rapids. At a greatly reduced stage a similar condition might conceivably arise at the exit of the Whirlpool or at the head of Foster Flats but it is believed that the foot of the Maid-of-the-Mist Pool will always be the critical point. Permits should be so worded that it is possible to stop all diversions for a short time to prevent the formation of impending ice jams. In 1908 an ice jam did form at this place during rather unusual conditions. The rising water did considerable damage at the Ontario Power Co.'s plant because their building was not designed for such a high stage of the pool. This defect has since been corrected and a similar rise would now do no harm. The other power houses in the Gorge were not seriously damaged.

Allowable diversion.—The most careful consideration of all the available evidence has led to the conclusion that 40,000 cubic feet of water per second may be diverted around the rapids at all times except possibly when an unusual combination of extreme low stage and extreme cold threatens the formation of a dangerous ice jam. Such a diversion will leave a flow of 167,000 cubic feet per second through the rapids at mean stage and it is expected that with this flow the scenic beauty of the rapids will be greater than at the present daily mean. At ordinary lowstage the flow through the rapids will be 110,000, which is sufficient as far as scenic effects are concerned. At the extreme low stages that occur for but a few hours in many years the flow would be reduced to 90,000 cubic feet per second; this is satisfactory as a minimum, but if intense cold weather should occur at the same time it might be desirable to reduce the diversion for a few hours.

This limit of 40,000 cubic feet per second for the diversion around the rapids is not necessarily permanent. After plants have been operating with such a diversion for some years observation may show that considerable increase in the diversion is allowable and desirable.

Power output of recommended diversions.—New plants designed on modern lines ought to give an output of at least 29½ horsepower per cubic foot per second if using diversions around the Falls and rapids both, and about 21 horsepower per cubic foot per second if using diversions around the Falls only. With the permissible diversions of 80,000 cubic feet per second around the Falls, and 40,000 around the rapids, the total power output would be just over 2,000,000 horsepower if the water were all used in new plants. If the present plants were retained the total output would be about 1,660,000 horsepower. Plans are now under way for replacing the inefficient Niagara Falls Power Co. plant and station 2 of the Hydraulic Power Co. As the demand for power grows and it becomes important to get the greatest possible output from every drop of water diverted it is reasonable to suppose that the inefficient plants on the Canadian side will also be replaced by better ones, and the output of 2,000,000 horsepower would ultimately be obtained.

5. DIVISION OF PROPOSED DIVERSION AND OF COST OF REMEDIAL WORKS.

Division of diversion allowed under present treaty.—The treaty between the United States and Great Britain, signed January 1, 1909, allows the diversion of the waters of the Niagara River above the Falls to the extent of 20,000 cubic feet per second on the American side and 36,000 cubic feet per second on the Canadian side. The reasons which led the commissioners to decide upon these particular limits are unfortunately not matters of record. A significant clause in the treaty states that it is the desire of both parties to limit the diversion of water from the Niagara River "with the least possible injury to investments which have already been made in the construction of power plants." As a matter of fact, the limits set by the treaty are very slightly greater than the total rights claimed by the companies which were actually diverting water at the time when the treaty was signed, if it be assumed that the right of the Niagara Falls Power Co. to double its present plant had expired from nonuse.

Considering all the evidence which is known to have been placed before the treaty commissioners, it appears probable that the limits set were based upon the projects of the companies which were then diverting water and not on any abstract opinions as to the respective rights of the two countries. As the object of the treaty was to prevent any great increase of the diversions without doing any harm to capital already invested, this method of dividing the diversion was at that time both satisfactory and just. The present question of how future diversions should be divided between the two countries rests on an altogether different basis, and the existing treaty therefore can hardly be said to form a precedent for determining the manner in which it should be divided between the two countries.

Conditions affecting the division of the proposed diversions.—The Niagara River, and in fact the whole Great Lakes system from Pigeon River to St. Regis, forms a water boundary separating the United States and Canada. The large topographical map accompanying this report, plates Nos. 13 and 14, shows the international boundary line from Buckhorn Island to Lewiston as it was located and marked by the International Waterways Commission. It is known to have been the intention of the framers of the treaty of Ghent, which laid down this boundary line, to divide the boundary rivers between the two countries with approximate equality. Of course, the men who framed this treaty were interested in the division of the water surface rather than of the flow. In general, the boundary line divides the flow between the two countries with approximate equality, but in a few places the division is very unequal. The greatest inequality is found near the head of Fosters Flats, where more than 80 per cent of the flow is on the United States side of the boundary, and at the crest of the Falls, where only about 6 or 7 per cent of the flow in the river is on the United States side.

It is evident that the diversion can not fairly be divided upon the basis of the division of the flowing water by the boundary line. The water is to be diverted around a reach of the river several miles in length. The diversion can only be divided in the ratio by which the boundary divides the flow of the stream at some one point, but at any other point the ratio would be quite different. Moreover, at the crest of the Falls the division will change as the crest recedes. It is quite possible that after 20 or 30 years the apex notch should

again be on the American side of the boundary, and ultimately the greater part of the flow over the crest line might be on the American side.

Another possible basis for the division is found in the ultimate source of the water. The latest studies indicate that about 52 per cent of the flow is derived from rainfall on the American side of the boundary line and 48 per cent from rainfall on the Canadian side. On this basis the United States would be entitled to a little more than half of the proposed diversion.

It is not believed that either of the principles outlined above affords a just and equitable method of dividing the diversion between the two countries. In fact, if not in law, the Niagara River is owned and used jointly by the two nations. Each has by treaty an equal right of navigation on both sides of the boundary. Neither can make any appreciable change in its part of the river without causing some change, either favorable or adverse, in the part belonging to its neighbor. If either country should attempt to exercise its "right" to take half the water of the river or all the water on its side of the boundary at any point, it would inflict irreparable damage on the other nation. Finally, the two countries must be considered to be joint trustees and custodians of the natural beauties of the Falls and rapids.

For these reasons it would appear that the only just and impartial method of dividing the proposed diversions is to award half of each, giving each the right to divert 20,000 cubic feet per second around the lower rapids and 40,000 cubic feet per second around the Falls. If experience shows that greater diversions are permissible at either place, these should also be divided equally.

Dividing cost of works.—There can be no question but that the cost of these remedial works should be divided equally between the two countries. The benefits are received by both sides. The preservation of the beauty of the Falls is to the joint benefit of both sides and can not be divided. If the diversions are divided equally the advantage to the two nations will depend only on the use which each makes of its respective share. The construction, of course, must be under the joint supervision of both.

ALBERT B. JONES,
First Lieutenant, Engineers, United States Army.

BUFFALO, N. Y., May 19, 1920.

From: Albert B. Jones, junior engineer.

To: The Division Engineer Lakes Division, Buffalo, N. Y.

Subject: Supplementary report on preservation of scenic beauty of Niagara Falls and of the rapids of Niagara River.

1. In my report on Preservation of Scenic Beauty of Niagara Falls and of the Rapids of Niagara River, submitted August 30, 1919, were numerous photographs showing the appearance of the Falls and rapids under various conditions of high and low water. These photographs were taken by Mr. W. S. Richmond, assistant engineer, in October, November, and December, 1917. It was the original intention to take three series of photographs illustrating conditions at high, mean, and low stage of the river. Excellent pictures were obtained at high and at mean stage, but weather conditions were such

that no extremely low-stage photographs could be obtained, and the "low-stage" series differed but very slightly from the pictures taken at mean stage.

2. In the spring of 1920 an extremely low stage of Lake Erie prevailed for several months, and during the third week of April a continuance of easterly winds reduced the flow of the Niagara River to an extremely small amount, smaller than had been observed for several years. On April 22 it was possible to get an excellent series of low-water conditions at the Falls. On the following day a westerly gale caused a decided rise in stage, and it has not since been possible to get photographs of low-water conditions in the Niagara Gorge.

3. The earlier pictures are published as photographs Nos. 73 to 104, inclusive, in the division engineer's report on Investigation of Water Diversion From the Great Lakes and Niagara River, Appendix C. They are referred to hereafter in this report as "photographs of the old series." These pictures show 11 views of the Falls and the rapids above the Falls, each view being represented by from one to five pictures taken at different stages. The amount of water flowing over the Falls in these pictures is as follows:

"High stage," 220,000 to 250,000 cubic feet per second.

"Mean stage," 160,000 to 165,000 cubic feet per second.

"Low stage," 155,000 cubic feet per second.

In the series taken on April 22, 1920, it was possible to get pictures of nine of these views. Two of the views—namely, "Canadian Rapids from Canadian side, looking upstream," and "East end of Canadian Falls from the Canadian end," could not be photographed because of heavy mist. The water flowing over the Falls when these pictures were taken varied from 125,000 to 140,000 cubic feet per second.

4. Photograph No. 130 is a panorama of the Falls taken from "Falls View," with 180,000 cubic feet per second flowing in the river and 135,000 cubic feet per second flowing over the Falls. It should be compared with photograph No. 73 of the old series, which shows the river slightly above mean stage, the flow over the Falls being 165,000 cubic feet per second. The most noticeable differences at the low stage are the bowlder shoals and isolated bowlders uncovered near each end of the Horseshoe Falls and in the Canadian Rapids. The bareness of the rock ledges at the ends of the Horseshoe is also shown, but this is more clearly illustrated in photographs Nos. 6 to 9. It is apparent that even at this very low stage the beauty of the American Falls is but little affected, especially when seen from this distant viewpoint.

5. Photograph No. 131 is a view of the American rapids above the Goat Island Bridge; river discharge, 185,000 cubic feet per second; flow over Falls, 140,000 cubic feet per second. It should be compared with photographs Nos. 74 to 77 of the old series. The comparison is somewhat obscured by the large amount of ice in the new picture, but it is fairly apparent that even this very great reduction in the flow over the Falls does very little damage to the scenic beauty of these rapids.

6. Photograph No. 132 shows the Canadian Rapids as seen from a point on Goat Island opposite the power house of the Toronto Power Co. The river flow when this picture was taken was 185,000 cubic

feet per second, and the flow over the Falls was 135,000 cubic feet per second. This picture should be compared with photographs Nos. 78 to 80 of the old series. The boulder beach in the foreground and the numerous boulders and small shoals in the middle of the rapids are the principal indications of the low water.

7. Photograph No. 133 is a view of the American Falls from the opposite side of the Gorge; discharge of river, 185,000 cubic feet per second; flow over Falls, 135,000 cubic feet per second. This should be compared with photographs Nos. 82 to 86 of the old series. The beauty of these Falls has been somewhat, though not greatly, diminished by the low stage. This is chiefly noticeable in the thinness of the water curtain at the right-hand end of the main fall, and also just to the left of the "ice mountain." A similar but lesser effect was visible to the eye at the left end of the Luna Falls or "Bridal Veil" and at the left end of the main fall. The camera failed to show this distinctly in the photograph. A comparison of photograph No. 4 with photograph No. 85 of the old series is particularly interesting. No. 85 was taken in 1906, when the total diversion was only about 15,000 cubic feet per second. No. 4 was taken in 1920, when the total diversion was about 50,000. The total river flow was almost exactly the same in the two cases, the estimated difference being less than 5,000 cubic feet per second. The difference between the two pictures, therefore, is an excellent measure of the effect of the increase of diversion in the last 13½ years upon the scenic beauty of the American Falls.

8. Photograph No. 134 is an attempt to show the American Falls from Goat Island. A heavy shower of mist was falling upon the camera and the picture is very poor. The discharge of the river at this time was 175,000 cubic feet per second, and the flow over the Falls was 125,000 cubic feet per second. This picture should be compared with photographs Nos. 87 to 90 of the old series. No. 90 was taken in 1906 at about the same river flow, but with a diversion of only about 15,000 cubic feet per second. Unfortunately it was not taken from exactly the same spot. As far as this very inferior photograph (No. 4) indicates anything it bears out the conclusions expressed in paragraph 7.

9. Photograph No. 135 is a panoramic view of the Horseshoe Falls taken from the head of the Terrapin Point path on Goat Island; river discharge, 185,000 cubic feet per second; flow over Falls, 140,000 cubic feet per second. This should be compared with photographs Nos. 91 to 94 of the old series. The ends of the Horseshoe Falls are the places most seriously affected by low-river stage or increased diversion, and the effect on these points is well shown in these photographs. In the foreground the "Goat Island Shelf" is shown nearly unwatered and covered with unsightly boulders. The flow over the extreme east end of the Falls has almost vanished. Toward the Canadian end are two complete breaks in the water curtain (directly under the left end of large building on the sky line). These discontinuities are not noticeable except at extremely low stages. The uncovered rock ledge at the Canadian end is barely visible through the mist, but is shown in the next picture. A comparison of No. 6 with No. 94 of the old series, taken in 1906, is particularly illustrative of the effect of increased diversion upon the scenic beauty of the Horseshoe Falls. These two pictures show the

river at exactly the same stage, but in the old photograph the total diversion was only about 15,000 cubic feet per second, while in the new one it is about 55,000.

10. Photograph No. 136 is a picture of the Canadian end of the Horseshoe Falls; river discharge, 180,000 cubic feet per second; flow over Falls, 135,000 cubic feet per second. It should be compared with photographs Nos. 95 and 96 of the old series. The contrast with the appearance at a very high stage as shown in No. 96 is especially striking. The white patches in the immediate foreground of this picture are neither ice nor water, but are a peculiar effect caused by the reflection of the sky on the wet rocks.

11. Photograph No. 137 shows the east end of the Horseshoe Falls, as seen from in front of the "Refractory," on the Canadian side. The river discharge was 180,000 cubic feet per second and the flow over the Falls was 135,000 cubic feet per second. This picture should be compared with photographs Nos. 97 to 99 of the old series. It shows very plainly the effect of diversion or low stage in denuding this end of the Horseshoe.

12. Photograph No. 138 is another view of the east end of the Horseshoe Falls taken from the edge of the cliff on Goat Island; river discharge, 185,000 cubic feet per second; flow over Falls, 135,000 cubic feet per second. It should be compared with photographs Nos. 102 to 104 of the old series. This illustrates in a most dramatic manner the effects already shown in photographs Nos. 6 and 8.

13. The nature and causes of the damage to the scenic beauty of Niagara Falls shown in this series of photographs have been described and explained at length in my report on the "Preservation of the Scenic Beauties of Niagara Falls and of the Rapids of the Niagara River," dated August 30, 1919. That report also states that these evils can be cured, and outlines a method of restoring the original beauty of the famous cataract, while allowing a much-needed increase in the amount of water used for power development. Nothing is brought out by these photographs tending to modify any of the conclusions of that report.

14. During the period of low water it was impracticable to obtain photographs of conditions in the rapids of the Niagara Gorge. However, in the late afternoon of April 22 a hasty reconnoissance from the Falls to Lewiston was made on a Gorge Route electric car. The effects of the extreme low stage upon the scenic beauty of the rapids was carefully observed by comparing the appearance of the rapids with the series of photographs taken in 1917. In some places the size and whiteness of breakers were reduced. In others new breakers and white water appeared where comparatively smooth rollers existed at ordinary stages. In many places no considerable change was noticeable. At one point, just below Fosters Flats, large rocks projected above the water, nearly in the center of the channel, where no indication of their presence was shown in the photographs. On the whole, it may be said that the scenic beauty of these rapids was neither materially increased or decreased when the river flow was reduced to about 175,000 cubic feet per second. Nothing was observed tending to modify any of the conclusions expressed in the report of August 30, 1919.

ALBERT B. JONES,
Junior Engineer.

APPENDIX D.

PROPOSITIONS FOR UTILIZING DIVERSIONS WITH GREATER ECONOMY.

[Section F of Mr. Richmond's report.]

1. GENERAL STATEMENT.

The localities where diversions of water from the Great Lakes system occur, and the character of the diversions, have been described already in sections A, B, and C of this report, the quantity of water diverted being stated for each case. These descriptions show that many of the diversions are not used as efficiently as they might be. There are also many places where diversions could be used very efficiently for navigation, sanitation, or power purposes, but where no water is now diverted.

The total amount of water diverted for navigation purposes is insignificant in comparison with that diverted for sanitary uses and power development. Any possible increase in the efficiency of its use for navigation would result in a totally imperceptible net gain, therefore this phase of the subject will not be considered further in this report.

With the exception of the diversions of the Sanitary District of Chicago, the same conditions obtains with respect to diversions for sanitary uses. In every other case of a diversion for sanitary purposes the water is returned to the Great Lakes Basin within a comparatively short distance and no serious injury to any interests results. The quantity of water pumped for water supply by the Chicago city waterworks in 1918 averaged 1,050 cubic feet per second, the maximum pumpage at any time being 1,315 cubic feet per second. This is much more than is used by any other city on the Lakes. Detroit is the second city in size in the Great Lakes region, and its average daily pumpage by the city waterworks is 220 cubic feet per second. It seems unnecessary to consider here what might be done to increase the efficiency of these diversions. The possibility of increased efficiency in the use for sanitary purposes of the diversions of the Sanitary District of Chicago has already been treated in Section B of this report.

In the matter of diversions for water power great increase in efficiency is possible. The diversion of the Sanitary District of Chicago could be made to yield much more power per cubic foot per second than at present. This has already been discussed in Section C. At Sault Ste. Marie, while the present plants are not particularly efficient, it appears that there is very little opportunity for increasing the efficiency economically. Along the St. Lawrence River there are several

places where considerable amounts of power could be obtained by proper development without serious damage to navigation or riparian interests. Small developments exist at most of these localities, but the only large-scale development along that portion of the river bordering United States territory is the one owned by the Aluminum Co. of America and its subsidiaries at Massena, N. Y. This is described in Section C. The water used in and along the New York State Barge Canal and the Welland Canal could probably be made to yield more power than it does at present. At Niagara Falls the greatest opportunity for increasing the efficiency of the use of diversions exists. It is toward this opportunity that the work of this investigation has been especially directed. The remainder of Section F will be devoted to the present and prospective power development at Niagara Falls. Reference is here made to the description of Niagara River given in Section A, and to the map and profile on plates 11, 13, and 14.

The total head available at Niagara Falls depends on the location of the works utilizing it. From La Salle to Lewiston the fall is about 317½ feet and from Port Day to the Devils Hole it is 303 feet. Any reasonably efficient scheme must lie within these limits. The most economical propositions develop about 313 feet. The Maid-of-the-Mist Pool below the Falls offers an opportunity to divide this head into two stages. The upper stage affords a head of from 223½ to 218½ feet, the lower one from 97 to 81½ feet. The above figures are taken at mean stage.

On the Canadian side three companies are developing the upper stage. One is fairly efficient, the other two are not. In addition, two small plants use a small amount of water under a fraction of the head. Another plant to utilize the full head is now under construction. On the American side there are two separate developments of the upper stage. One is very inefficient, not altogether through the fault of those responsible for the development; the other is the most efficient plant of all, and is now being extended to increase its capacity considerably, at the same time slightly improving its average efficiency.

With the Canadian plants, except as to their total diversion of water and exportation of electrical energy, the United States has nothing to do. A general description of them has been given previously in section C of this report. On the United States side the present diversion allowed by treaty is 20,000 cubic feet per second. Various methods of using this water will be considered and the matter of using any greater diversions which may be permitted in the future will be taken up.

Since the inception of the Hydraulic Canal project some 75 years ago, scores of propositions for the development of Niagara power on a large scale have been advanced. Some were based on sound engineering knowledge and a broad grasp of the situation, and others were freakish and grotesque in the extreme. Several of the best schemes have been worked out rather completely during the course of this investigation, outline plans have been prepared, and estimates of the cost and the power output have been made. More than 20 other projects have been studied in more or less detail. The latter are mentioned in the report to the extent that their impor-

tance seemed to justify in each case. The plans and estimates were based on a diversion of 20,000 cubic feet of water per second and a stage of water surface in the river coincident with the mean stage for the 51 years ending 1910. The Niagara River profile compiled by the United States Lake Survey in 1912 was used, with corrections to the lower river profile obtained in 1917. (See pl. No. 11.) Distances, elevations of the ground surface, and depths of water in the river were obtained chiefly from the surveys made for this investigation and from Lake Survey manuscript charts. The published charts of the Lake Survey and Geological Survey and other maps were also used. Elevations of the rock surface were derived from rock soundings made for this investigation and from those made by the Board of Engineers on Deep Waterways.

A great deal of time was spent in determining the proper unit costs to be used. Manufacturers of hydraulic and electrical machinery submitted estimates of the cost of the various mechanical installations. The experience of engineers of various power companies, the city engineer of Niagara Falls, and other engineers and contractors accustomed to dredging, excavating, tunneling, or building along the Niagara frontier was drawn upon. A detailed analysis of the elements entering into the cost of various operations was made. From the Federal Employment Agency and several large employers of labor data as to rates of wages were secured. Current prices of materials and equipment were obtained from various sources. The United States Railroad Administration gave freight rates for transportation of machinery.

The proper determination of costs was greatly complicated by the rapid and almost continuous advance in price during the past few years of many classes of commodities and of labor. Most published engineering cost data pertain to a period when common labor was paid 15 cents an hour, cement cost \$1 to \$1.40 per barrel, and steel shapes cost approximately \$1.75 per hundred pounds. In October, 1918, labor was scarce at 50 cents an hour, cement cost from \$2.50 to \$3 per barrel, and steel shapes cost over \$4 per hundred. The prices of many important materials fluctuate violently from month to month. The estimates given herein are based on conditions as of October, 1918. Because of the apparent importance of speed of development most of the construction items were figured on a basis of three 8-hour shifts per day. The unit prices are the prices at which it is assumed contracts would be let. They thus include contractors' profits, liability insurance, and expenses of organization and administration. To these have been added 10 per cent for engineering, inspection, accounting, and general overhead construction expenses, and 15 per cent for contingencies, including incompleteness of the design on which estimates are based—damages, omissions, losses, labor troubles, delays, and other unforeseen and unpreventable causes of extra expense. The complete estimates include cost of real estate and interest during construction, but do not include cost of promotion, financing, organizing, buying out the rights of other companies, or purchasing and installing transformer and transmission equipment. The important items of this nature are treated in Section F 10.

The schedule of unit prices adopted is given in table No. 28, which is self-explanatory except for the prices on tunnel excavation. The

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smaller tunnels were of circular cross section. The larger tunnels were of horseshoe cross section, with the following characteristics: Height equal to horizontal diameter at mid height; roof arch a semi-circle of radius equal to semidiameter; sides tangent to roof arch and of radius equal to twice the diameter, or four times the radius of roof arch; invert of radius twice the diameter. The thickness of lining was assumed to vary with the net diameter according to table No. 29.

TABLE No. 28.—Schedule of unit prices adopted.

Class and description of work and materials.	Unit.	Unit price as of Octo- ber, 1918.
Earth excavation:		
Small jobs, less than 10,000 cubic yards.....	Cubic yard.....	\$1.50
Small jobs, less than 10,000 cubic yards, in cofferdam.....	do.....	2.00
Jobs of 10,000 to 300,000 cubic yards.....	do.....	1.25
Jobs of 10,000 to 300,000 cubic yards, in cofferdam.....	do.....	1.75
Long canals, very large yardage, including hardpan.....	do.....	.65
Back fill.....	do.....	.45
Rock excavation:		
Small jobs, less than 10,000 cubic yards.....	do.....	3.75
Small jobs, less than 10,000 cubic yards, in cofferdam.....	do.....	4.25
Jobs of 10,000 to 300,000 cubic yards.....	do.....	3.00
Jobs of 10,000 to 300,000 cubic yards, in cofferdam.....	do.....	3.50
Deep wheel pits.....	do.....	5.00
Shafts.....	do.....	12.00
Power-house site, below cliff.....	do.....	3.50
Power canal with channeled sides, including channeling.....	do.....	2.25
Ship canal, 200 feet wide, channeled sides, including channeling.....	do.....	2.00
Ship canal, 300 feet wide, channeled sides, including channeling.....	do.....	1.95
Ship canal, 400 feet, wide, channeled sides, including channeling.....	do.....	1.90
Lock pits.....	do.....	2.25
Riprap.....	do.....	1.00
Dredging:		
Hardpan in river.....	do.....	1.25
Rock in river.....	do.....	6.50
Rock in hydraulic canal.....	do.....	25.00
Cofferdams, timber, rock filled, timber sheeted (D=depth of water).....	Linear foot.....	D ² .40
Concrete:		
Minor jobs, less than 10,000 cubic yards.....	Cubic yards.....	15.00
Power-house substructure, locks, plain walls, and linings, 10,000 yards or more.....	do.....	12.00
Reinforced arches, columns, beams, 1 per cent reinforcement.....	do.....	25.00
Reinforced concrete, cost of reinforcement not included.....	do.....	15.00
Reinforcing steel, each per cent per cubic yard of concrete.....	do.....	10.00
Road pavement.....	Square yard.....	3.00
Tunnels:		
Drift at top, 8 feet wide, 9 feet high, usually timbered.....	Cubic yard.....	15.00
Heading, top, down to level 6 feet below drift, usually timbered.....	do.....	9.00
Bench, not timbered.....	do.....	4.00
Concrete lining.....	do.....	14.00
Steel:		
Iron and steel, common or plain shapes, not fabricated.....	Pound.....	.07
Racks, penstocks, frames, etc., fabricated and erected.....	do.....	.10
Steel castings.....	do.....	.12
Steel forgings.....	do.....	.20
Other metals, bronze.....	do.....	.50
Oak fenders, etc., fabricated and placed.....	M feet b. m.....	150.00
Gates, including settings, mechanisms, and motors, per square foot of full opening.....	Square foot.....	30.00
Buildings:		
Power houses, complete with cranes, ventilating and heating equipment, lighting installation, and elevators.....	do.....	15.00
Gate houses, etc., with cranes, lighting, heating, and ventilating systems.....	do.....	12.00
Bridges:		
Class A, country roads, clear span 56 feet, length 65 feet, width 18 feet.....	Bridge.....	4,000.00
Class B, main roads and city streets, span 56 feet, length 65 feet, width 27 feet.....	do.....	8,000.00
Class C, main roads and city streets, two trolley tracks, length 65 feet, width 60 feet.....	do.....	35,000.00
Class D, single-track railway, clear span 56 feet, length 65 feet.....	do.....	20,000.00
Class E, railway with two or more tracks, 65 feet long, per track.....	Track.....	18,000.00
Class F, electric railway with two tracks, length 65 feet.....	Bridge.....	18,000.00
Swing, bascule, and fixed bridges for ship canal, not given in detail.....	do.....	
Switchboards—switches, switchboards, busses, connections to generators, and mechanisms.....	Kilowatt.....	2.25

TABLE No. 28—Schedule of unit prices adopted—Continued.

Generating units.

[Includes turbines from penstock connection to concrete draft tube, generator on same vertical shaft, with Kingsbury bearing and individual exciter and governor.]

Case.	Head.	Maximum capacity.	Revolutions per minute.	Price f. o. b. factory.		Freight and erection per unit.	Freight and erection per horse-power.	Freight, erection, and switch gear per horse-power.
				Per horse-power.	Per unit.			
	<i>Feet.</i>	<i>Horse-power.</i>						
1	90	15,500	125	\$16.00	\$248,000	\$19,000	\$1.23	\$3.48
2	90	22,000	100	15.50	341,000	20,000	1.18	3.43
3	216	39,000	150	15.00	585,000	44,000	1.13	3.38
4	300	22,000	250	14.50	319,000	24,000	1.09	3.34
5	300	39,000	214	14.10	550,000	41,000	1.06	3.30

Johnson valves.—Head, 100; cost in place, \$43,000. Head, 200; cost in place, \$53,000. Head, 300; cost in place, \$63,000.

TABLE No. 29.—Thickness of concrete lining in tunnels.

Net diameter of tunnel.	Net thickness of lining.	Average gross thickness of lining.
<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
4	1.38	1.88
8	1.42	1.92
12	1.46	1.96
15	1.50	2.00
16	1.51	2.01
20	1.56	2.06
25	1.63	2.13
30	1.72	2.22
35	1.83	2.33
40	1.98	2.48
45	2.20	2.70
50	2.50	3.00

The average thickness of concrete assumed as necessary to line the overbreak was one-half foot. Excavation yardage was computed to the average overbreak line. It was assumed that in each case a drift 9 feet high and 8 feet wide would first be driven on the center line at the top of the excavation, this work to cost \$15 per cubic yard, including such timbering as found necessary. The drift was to be followed by a heading completing the excavation down to a horizontal line, 15 feet below top of drift, and costing \$9 per cubic yard, including any necessary timbering. The balance of the excavation was taken as bench work at \$4 per cubic yard. Plain concrete lining was assumed at \$14 per cubic yard. On these assumptions the costs of tunnels per linear foot were computed to be as given in Table No. 30.

TABLE NO. 30.—*Estimated cost of tunnels per linear foot.*

Section.	Net diameter.	Cost.	Section.	Net diameter.	Cost.
	<i>Feet.</i>			<i>Feet.</i>	
Circular.....	4	\$44	Horseshoe.....	25	233
Do.....	8	84	Do.....	30	365
Do.....	12	127	Do.....	35	450
Do.....	16	169	Do.....	40	545
Do.....	20	213	Do.....	45	660
Horseshoe.....	15	167	Do.....	50	794
Do.....	20	225			

Costs for intermediate diameters were interpolated. In the case of tapering sections of tunnel, 10 per cent was added to tabulated cost for mean diameter. For circular tunnels of steep slope, when more than 20 feet in diameter, or for vertical circular risers of similar size and thickness of lining, the price taken was 150 per cent of the tabulated cost of horseshoe tunnels of equal net diameters.

In arriving at the construction costs given in subsequent parts of this section it was necessary in each case to assume a fixed set of conditions. The conditions peculiar to each case are, for the most part, embodied in the outline designs, which define in a general way the required construction, materials, and equipment, the fundamental assumptions common to all the projects, in addition to the unit costs and tunnel characteristics already explained, are as follows: (1) That each project should provide for the utilization of 20,000 cubic feet of water per second in approximately the most economical manner consistent with requirements of the project. (2) That economic design should be based on an assumed value of electric energy on the bus bars of \$15 per horsepower supplied continuously for one year. In this connection it must be borne in mind that the cost factors omitted, namely, promotion, financing, organizing, purchase of rights, and purchasing and installing transformer and transmission equipment, would add considerably to this figure, making the cost at any customer's premises \$16 to \$20 under very favorable circumstances. (3) That sufficient funds could be secured at an interest rate of $5\frac{1}{2}$ per cent per annum. (4) That a depreciation allowance of $2\frac{1}{2}$ per cent of the entire construction cost to date would be set aside annually in a depreciation reserve. (5) That the annual taxes and insurance charges against the productive portion of the plant would be 2 per cent of the cost of such productive portions. (6) That the assumed prices of parcels of land and of rights of way were sufficient to cover agents' and lawyers' fees and costs of any necessary condemnation proceedings. (7) That no taxes would be assessed against incomplete or nonproductive works, and any taxes assessed against nonproductive lands would be charged to contingencies. (8) That machinery installed in the power houses would be of sufficient capacity to carry full load in each power house with one unit shut down, the generators being able to carry full turbine load at 90 per cent power factor. (9) That the over-all efficiency of turbine and generator combined would be 86 per cent, including excitation and all hydraulic losses from lower end of penstock to tail-water beyond draft tube. (10) That construction would be rushed, most of the work being done in three 8-hour shifts per day.

(11) That the market for power would build up with sufficient rapidity to absorb all the power as soon as it could be produced.

In the hydraulic computations the Kutter formula was used, the value of "N" being taken at 0.013 for tunnels lined with concrete, 0.028 for canals in rock with channeled sides excavated in the dry, and 0.050 for the Hydraulic Canal deepened by dredging.

The stated power outputs of the various plants are for electric energy at the bus bars, the characteristics being 12,000 volts, 3 phase, 25 cycles per second. Power is based on continuous operation of the plant in good condition and at best efficiency. The full diversion of 20,000 cubic feet of water per second is assumed to be used and mean river stage to prevail, as previously stated. The fact should not be ignored that the extreme range of river stage at Port Day is from about 559 to about 566, the mean being 562. The range in the Maid of the Mist Pool is about four times as great, and in the same direction. At the site of proposed power houses in the lower gorge the fluctuation is about two and one-half times what it is at Port Day. All elevations given in this report are in feet above United States standard datum, the zero of which refers to elevation of mean tide at New York, and they are based on the adjustment of this datum made in 1903.

In regard to the schemes which have been worked out rather completely it should be stated that the intent was to prepare outline layouts and designs in sufficient detail to give in each case a definite basis for a fair estimate of the construction cost. Great pains were taken that all essential major details should be in accord with sound engineering principles and should be thoroughly practical. Beyond this it was not intended to go. The plans described and illustrated are not final designs. All minor details are omitted. The outline designs are made angular to simplify computation of quantities. In case any one of these projects should be adopted it would be necessary to design carefully and in detail each essential feature. What seemed to be the best ideas and suggestions from whatever source were utilized. Acknowledgments in detail are considered out of place in the main portion of such a report, but are given in general terms in Appendix K. The outline drawings are best designated as sketches and are intended only to illustrate the main features of each scheme for which an estimate of cost was prepared.

In determining the most economical size of tunnel, canal, or other structure of prime importance the principle followed was that greatest economy was secured by using the size which made the sum of the annual fixed charges upon it and the annual value of power lost because of it a minimum. Economical sizes were not determined with great exactness; partly because it was believed that tunnels and canals at Niagara Falls should be made a little larger than present economy demands, both to provide more power, even if at a slightly higher rate, and to anticipate improvements in the shorter lived generating machinery; partly because best economy was dependent not only on the estimated construction costs and fixed charges, but also on the assumed selling price of electrical energy, and partly because preliminary computations on the estimates had in some cases progressed beyond the point of fixing economical sizes before the final unit prices and percentage fixed charges had been adopted and recomputation was deemed an unwarranted refinement.

The differential surge tanks provided in several of the estimates were calculated to regulate hydraulic conditions involved in starting up one unit at a time and in shutting down the entire plant suddenly. Provision was made to hold all the water in the tank in the second case, although the tank might be somewhat less expensive if designed to waste a portion of it.

In computing time of completion and interest during construction it was assumed that the machinery and electrical equipment of one unit could be procured, installed, and made ready for operation in one year, and the other units one every three months thereafter. This assumption was based on statements made by manufacturers. Other time estimates were based on the progress made on similar jobs.

The estimates which follow are believed to form a satisfactory and reliable basis for comparing the cost of the different propositions considered. The actual cost of any future plants will depend to a very large extent upon the future prices of labor and materials, which in the present unsettled state of affairs can not be forecast. Had the state of the science and art of hydroelectric practice been such that similar plants could have been built in 1908 the cost would have been only about 40 per cent of the cost in 1918. To predict whether costs will continue to rise or will tend to approximate the old values is, of course, impossible.

2. PRESENT NIAGARA FALLS PLANTS.

Early history.—The first recorded use of the water power of the Niagara River was in the year 1725, when a French settler is said to have built a small sawmill on the edge of the rapids just above the Falls. During the century that followed various similar installations were made, until, in 1825, three gristmills, two sawmills, and a paper mill were operating on Niagara River power. These were all crude affairs, utilizing but a few feet of head and an insignificant fraction of the water to generate the power required to satisfy the modest needs of a frontier village. Mills of this type continued to be built from time to time during the middle years of the nineteenth century, but the possibility of power development on a grander scale was early realized by farseeing men. De Witt Clinton, the father of the Erie Canal, in 1810 wrote in his journal that Niagara Falls is "the best place for hydraulic works in the world." In 1853 the construction of the Hydraulic Canal, the first large-scale project, was commenced, and in 1872 the first mill on this canal began to operate. The year 1879 marks the first use of Niagara power to generate electricity. The construction of the first large, modern electric station was begun in 1890 and was completed in 1895. This was followed by two more stations, and in 1914 the American power plants reached their present state of development. Photograph No. 139 is of one of the earlier developments. It shows in the upper view the paper mill on Green Island as it existed in 1885, and in the lower view the appearance of the same site after restoration of the natural scenery by the park commission. Photograph No. 140 is a reproduction of an old map of Niagara Falls, showing the location of power developments then existing and the proposed location of the Hydraulic Canal.

History of the Hydraulic Power Co.—The earliest suggestion of what was afterwards known as the Hydraulic Canal seems to have come from Augustus Porter in 1842. Five years later he and Peter Emslie, a civil engineer, published a plan for such a work. On March 22, 1853, the Niagara Falls Hydraulic Co. was incorporated. Its paid-up capital stock was \$500,000, which it was authorized to increase to \$5,000,000. Its president was Caleb S. Woodhull, ex-mayor of New York City, but Horace H. Day soon became the moving spirit of the concern, and the completion of the canal was largely due to his energy and persistence. The project comprised a canal 70 feet wide and 10 feet deep, about three-quarters of a mile long. The canal was to start from a point about 1 mile above the Falls and terminate in a basin near the edge of the Gorge about half a mile below the Falls. The basin was to be about half a mile long, and between it and the edge of the cliff were the mill sites, where the water was to be used under moderate heads and then spilled over the cliff. The estimated capacity of the canal was 2,436 cubic feet per second. The works projected, including the route of the canal as finally constructed, are shown on photograph No. 140.

The company acquired a 100-foot right of way for the canal from the Porter family and about 80 acres of land for mill sites. The route was surveyed by E. R. Blackwell, civil engineer, of Buffalo, and a contract for the excavation was let to Latham, Gage & Hawes for the sum of \$186,000. Construction began on April 20, 1853. Water was admitted in 1856, and the canal was considered complete in 1861. As actually constructed, it was only 36 feet wide and 8 feet deep. The official opening of the canal in 1857 was the occasion of a popular celebration, three small steamers formally opening navigation from the upper Niagara River to Port Day, at the head of the canal. There the enterprise came to a standstill. During the next 16 years only one small tenant was obtained to utilize the company's power. This was a small flour mill, developing 150 horsepower under 25 feet head, which was built in 1872 by C. B. Gaskill. It is now owned and operated by the Cataract City Milling Co. Lack of market for the power bankrupted the company, and the stockholders' investment, about \$1,000,000, was practically a total loss.

In 1877 Jacob F. Schoellkopf, of Buffalo, and A. M. Chesbrough bought the rights and property of the Niagara Falls Hydraulic Co. at a very low figure. The following year Schoellkopf bought up Chesbrough's interest and organized the Niagara Falls Hydraulic Power & Manufacturing Co. with a capital of \$10,000. An important part of the consideration that Chesbrough received for his interest was a mill site between the basin and the cliff and the right to draw from the basin an amount of water "equal to 900 horsepower under a head of 50 feet." Two days later Chesbrough sold this land and water right to Capt. Charles B. Gaskill. Gaskill built a grist mill on his new property. From this grant the Pettebone-Cataract Paper Co. derives most of its present rights.

Not long afterwards the Schoellkopf interests built a flour mill, which is still operating and is known as the Schoellkopf & Matthews Mill. In 1880 a paper mill leased land and water power, and from that time on the number of tenant companies and the amount of power developed increased rapidly. The first water wheel had been installed under a 25-foot head, but as the design of wheels improved

the head was increased to a maximum of nearly 100 feet, and in some instances the tail water from one installation was collected and passed through another wheel.

In 1881 the Niagara Falls Hydraulic Power & Manufacturing Co. installed electric generators in what came to be called its Station No. 1, and sold electric power to various manufacturers and to the village. This marks the first commercial development of electric power at Niagara, although the Falls and park had been illuminated by a small private electric plant two years previously. Station 1 contained three units, operating under a head of 75 feet, and developing a total of 1,800 horsepower. This plant was later leased to the Cliff Paper Co. During the eighties and early nineties a very considerable industrial district was built up in the vicinity of the basin, consisting chiefly of flour mills, paper mills, and electroplating establishments.

In 1892 the enlargement of the canal to a width of 70 feet and a depth of 14 feet was commenced. Meanwhile the rapid development of electrical and hydraulic machinery and of electrochemical processes and the example set by the immense project of the Niagara Falls Power Co. led the company to undertake the generation of electricity on a larger scale. In 1895, the year when the Niagara Falls Power Co. first began to generate power, the Niagara Falls Hydraulic Power & Manufacturing Co. began the construction of a new power house, known as Station No. 2. This was the first installation on the canal which was designed to use the total available head. It was built at the foot of the cliff and received its water by penstocks from a fore bay connected with the basin by two flumes. It contained 16 turbines, with a total rated capacity of 31,250 horsepower. These drove 31 generators, with a total rated capacity of 22,980 kilowatts. The turbines were owned by the power company, but most of the generators were the property of the Pittsburgh Reduction Co., which purchased mechanical power from the water power company. This plant first delivered power in December, 1896, and was completed in 1901. Photograph No. 141 is of the fore bay and photograph No. 142 of the power station of this development while under construction. As illustrating one of the difficulties which had to be contended with, photograph No. 143 is given, showing the roof of Station No. 2 crushed in by ice falling from the face of the cliff. One-third of the machinery was covered with ice and débris. The company was put to considerable expense, both to repair the damage and also to build a high masonry wall for retaining the ice.

The closing years of the nineteenth and the opening years of the succeeding century saw a vast development of the electrochemical industries which was, in no small measure, inspired by the large amounts of cheap electric power available at Niagara Falls. These years saw the invention or commercial development of the processes for making aluminum, calcium carbide, carborundum, artificial graphite, and other products which before had been either unknown or known only as rare and expensive curiosities. These new industries were largely dependent upon the Niagara electrical developments, and the demand for power soon outran the capacity of the plants. In 1904 a new power plant, station 3, was begun, together with a further enlargement of the canal. Station 3 followed the general plan of station 2, but had larger and more efficient machines,

and, in general, embodied the most recent advances of hydraulic and electric engineering. Its 13 turbines had a rated capacity of 130,000 horsepower. The first unit in this plant began to operate in September, 1907, and the thirteenth, or last, unit in August, 1914. In the meantime the company had changed its name to "Hydraulic Power Co."

The Burton Act, approved June 29, 1906, and the permit subsequently issued by the Secretary of War, limited the amount of water the company could divert from Niagara River to 6,500 cubic feet per second. As a given amount of water would develop much more power in the new electric stations than in the low-head developments of the tenant companies, the latter were gradually induced to exchange their old water-power rights or leases for supplies of electric power. At present there is only one company, the Pettebone-Cataract Paper Co., which, together with its subsidiary, the Cataract City Milling Co., retains the right and continues to use water from the basin under a comparatively low head. The history and plant of this company will be described later.

Present plant of Hydraulic Power Co.—On plate No. 28 is a map showing the location of the hydraulic canal and basin, the two power plants of the company, and their relation to the Falls. The entrance of the canal at Port Day is about 200 feet wide. This is diminished in the first 400 feet to a width of 100 feet at the Buffalo Avenue Bridge, which width is maintained to the basin. The depth in the tapering section varies from 12 to 16 feet. The company is now engaged in deepening it. In the river outside of the entrance are various piers designed as anchorages for wooden booms whose purpose is to prevent the entrance of ice into the canal. The company is now replacing these by more extensive structures of the same kind and is dredging a deeper channel from the canal entrance out into deep water. The depth of the canal itself varies considerably, the mean being about 16 feet at ordinary stages. The canal was cut through a hard limestone formation, the so-called Lockport dolomite. Its sides and bottom are very rough and uneven as a result of successive enlargements which have been accomplished by drilling, blasting, and dredging under water. Hydraulic measurements by the Lake Survey in 1914 showed a value of "Kutter's N" of about 0.050. The length of the canal is about 4,700 feet.

The basin at the lower end of the canal runs parallel to the cliff, spreading out in both directions from the line of the canal. It is about 70 feet wide and 800 feet long. On plate No. 29 are shown the basin, its connections, and the power houses. From the south end of the basin two covered flumes about 170 feet apart and 270 feet long carry the water for station 2 to a fore bay under the gate house near the edge of the cliff. Near the center of the basin two covered flumes carry water to the wheels of the Pettebone-Cataract Co. and Cataract City Milling Co. From the north end of the basin a concrete-lined canal 50 feet wide leads under the road and railroad, some 300 feet, to the fore bay of station 3, at the edge of the bluff.

Station 2 is a rectangular building at the foot of the cliff below its fore bay. It is about 110 feet wide and 165 feet long. From the racks and gates at the fore bay the water is led over the edge of the cliff and then vertically down to the power house in two steel penstocks 11 feet in diameter. The 8-foot penstock which formerly sup-

plied four wheels in the north end of the power house has been removed. The penstocks run horizontally under the power house and terminate near its western wall, where they are supplied with air chambers and relief valves. Vertical branches from the penstocks rise to the nine turbines on the floor above, five of which are fed by one penstock and four by the other. The turbines are of the horizontal shaft type with cylindrical cases, double runners, and two draft tubes. They range in rated output from 2,300 to 2,900 horsepower each, with the total of 23,600 horsepower.

Each turbine drives two generators, direct-connected, one on each side. These are direct-current machines, with a total rated capacity of 15,750 kilowatts. They are connected in parallel and supply current at 330 volts, which is transmitted to the top of the cliff, where it is used in plant No. 2 of the Aluminum Co. of America.

The 50-foot canal from the north end of the basin passes first under a gatehouse, southeast of the railroad track, where there are three large gates that can be closed for unwatering the fore bay. Then, passing under the tracks, it makes a bend of about 70° to the right. On the outside of this curve are the three 16-foot gates of the ice run. A steel girder across the canal dips several feet into the water and diverts floating ice and trash toward the ice run. The canal then enters the gatehouse, where it forms a fore bay 400 feet long, 50 feet wide at one end and 15 at the other, and 22 feet deep. A continuous row of racks runs along the west side of the fore bay, and behind them are the bell-mouthed entrances of the 15 penstocks. Each penstock is provided with gate, air vent, by-pass, and drain. Besides housing the fore bay and its appurtenances, the gatehouse contains a machine shop, a small transformer station, and the offices of the company. All the buildings are of a rough-stone masonry that harmonizes with the face of the cliff and has a very attractive appearance. A great wall of the same masonry hides the 15 steel penstocks which descend the cliff to station 3. Thirteen of these penstocks are 9 feet in diameter, and the other two, serving the exciters, are 5 feet each. Station 3 is a masonry building 100 feet wide and nearly 500 feet long, divided by a longitudinal partition into a turbine room adjacent to the cliff and a generator room toward the river.

The turbines, built by I. P. Morris & Co., are of the horizontal shaft type, with cast-iron scroll cases, double runners, wicket gates, double draft tubes, and bursting plates. There are 13 turbines of 10,000 horsepower, each of which is served by one of the 9-foot penstocks. Together they total 130,000 mechanical horsepower. Each of the two 5-foot penstocks serves a 1,000-horsepower I. P. Morris turbine similar to the large machines, but having single, unbalanced runners, and only one draft tube apiece. They are used to drive the exciters.

The draft tubes discharge into tailrace passages 18 feet wide and 68 feet long, which run transversely under the power house, each race having a weir at its outer end over which the water from the turbine is discharged into the river, and by means of which the water surface in the tailrace is held sufficiently high to seal the draft tube. The weirs and turbine settings were constructed at such an elevation as to leave about $3\frac{1}{2}$ feet of the total available head undeveloped under average conditions.

The turbines are numbered successively from 1 to 15, beginning at the south end. Nos. 1, 2, 4, 5, 6, 7, 9, and 10 each have a single alternator on the shaft in the generator room. These are Allis-Chalmers generators of the Bullock type, with internal revolving fields, and they operate at a speed of 300 revolutions per minute, delivering 3-phase current at 25 cycles and 12,000 volts. Each has a rated capacity of 8,500 kilovolt amperes. Turbine No. 3 drives one 250-volt, 3,000-ampere, direct-current generator at 450 revolutions per minute. Turbine No. 8 drives two fairly similar machines. These three generators furnish the exciting current for the fields of the alternators.

Turbines Nos. 11, 12, 13, 14, and 15 each drive two General Electric Co. direct-current generators, direct-connected on the shaft. These machines, which are rated at 3,500 kilowatts each, operate at about 650 volts and 300 revolutions per minute. They are operated in parallel.

Along a gallery behind the generators are the gate-control mechanisms and governors. On the opposite side of the generator room are two galleries carrying the switchboards, control desks, and station instruments. The equipment on one gallery pertains to the alternating-current generators and exciters, while that on the other pertains to the direct-current generators. The oil switches, reactors, instrument transformers, and all other bulky or high-tension accessories are on the main floor or in the basement. Plate No. 30 shows a typical cross-section of station 3.

The static transformers are in the gatehouse building. These are step-down transformers, as all transmission is either at generator voltage, 12,000, or at a lower voltage. Near plant No. 2 of the Aluminum Co. is a substation where several rotary converters are operated. These are fed from the alternating-current commercial lines, and produce direct current for use in near-by factories. The Aluminum Co. also has a rotary substation near its plant No. 3, where some of the alternating current is converted into direct current at 650 volts for use in that plant.

The Hydraulic Power Co. owned no electric machinery and produced no electric power. It owned the turbines and sold mechanical power to the Cliff Electrical Distributing Co. and the Aluminum Co. of America. The generators in station 2 belong to the Aluminum Co. and are operated by them, their output being used entirely in Aluminum plant No. 2, which is directly above the power house. In like manner the Aluminum Co. owns and operates the direct-current equipment in station 3 and uses the electric power at the top of the cliff in its plant No. 3. The alternating-current machinery and equipment in station 3 was the property of the Cliff Electrical Distributing Co., which transmitted electrical energy and sold it to many industrial concerns in and near the city of Niagara Falls. The transmission lines of this company were almost wholly in underground conduits, and the most distant transmission was to the Electro-Metallurgical Co., about 3 miles.

Station 2 was designed more than 20 years ago, and is much less efficient than a modern plant would be, although there are only two stations at Niagara Falls which produce more horsepower per cubic foot of water diverted, namely, station No. 3 of the Hydraulic Power Co. and the plant of the Ontario Power Co. The turbines

and the alternating-current machinery in station 3 are very much more up to date. While a plant built to-day would contain units of two or three times the capacity, these would be only a very small percentage more efficient than the units in station 3. The direct-current generators in station 3 are among the largest direct-current machines every built. The design of machines of such large capacity and low voltage involves many difficult problems. Their efficiency is therefore considerably less than that of the alternating-current machines. The use of large direct-current generators will probably be avoided in any future developments.

The efficiencies of various divisions of the plant were obtained in November, 1914, by an elaborate set of tests conducted under direction of the United States Lake Survey. Table 31 gives the results, expressed in horsepower developed per cubic foot per second of water used, and also as a percentage of the total horsepower per cubic foot per second theoretically represented by the overall head of 219 feet, namely, 24.85 horsepower. The theoretical horsepower per cubic foot per second between Lake Erie and Lake Ontario at mean stage is 37.03, the head being 326.35 feet.

TABLE NO. 31.—*Efficiency of hydraulic plant of Niagara Falls Power Co.*

Division of plant.	Efficiency at best load.	Horsepower per cubic foot per second at best load.
	<i>Per cent.</i>	
Direct current station 2	57	14.2
Direct current station 3	75	18.6
Alternating current station 3	80	19.9

Photographs Nos. 144 to 154, inclusive, are presented as illustrative of the main features of this development, either under construction or after completion. Explanations are given under each picture.

A brief history of the diversions of water from Niagara River through the Hydraulic Canal from the time the Secretary of War began supervising diversions to date has been given in Section C of this report, and need not be repeated here, except to state that the present diversion varies between 7,500 and 8,500 cubic feet per second, and that it is expected that about 9,500 will be utilized soon through the use of machinery now in process of fabrication and installation.

On October 31, 1918, the Hydraulic Power Co. and its subsidiary, the Cliff Electrical Distributing Co., merged with the old Niagara Falls Power Co., forming a new company named the Niagara Falls Power Co. This merger, unsuccessfully attempted previously, was brought about largely through the efforts of the War Department. At the time of the merger the capital stock of the Hydraulic Power Co., issued and outstanding, was \$12,000,000, and the outstanding bonded indebtedness was \$6,500,000. The Cliff Electrical Distributing Co. stock amounted to \$500,000, and the outstanding bonds amounted to \$1,150,000. The new company is authorized by the State of New York to divert from above the falls as much water as the Hydraulic Power Co. and Niagara Falls Power Co. together

were permitted to divert under State authority, and discharge the same into the Maid of the Mist pool, but not farther down stream than 1,000 feet below present Station No. 3 of the Hydraulic Power Co.

Pettebone-Cataract Paper Co.—The Pettebone-Cataract Paper Co. is the only other company that still retains a right to take water from the Hydraulic Canal. It has succeeded to the right mentioned previously to draw from the basin an amount of water "equal to 900 horsepower, under a head of 50 feet." This was a perpetual right granted to C.B. Gaskill "and to his heirs and assigns forever." By an arbitration in 1884 it was decided that the amount described in the deed was equivalent to 189.2 cubic feet per second. In addition, this company has leased from the Hydraulic Power Co. the right to a small additional diversion. The quantity now supposedly used by the Pettebone Co. is 219 cubic feet per second, and by the Cataract City Milling Co. 52 cubic feet per second. The more northerly of the two covered flumes leads to the water wheel of the Pettebone-Cataract Paper Co., which operates under 90 feet of head. Served by the other flume is a second wheel of the same company, and the wheel of the Cataract City Milling Co., each acting under 86 feet of head. It is improbable that these wheels develop more than $7\frac{1}{2}$ horsepower per cubic feet per second which corresponds to an over-all efficiency of 30 per cent. Photograph No. 144 shows the discharge from the wheels of this company, high up the gorge, and gives a good idea of the wasteful use of water in which this company persists.

History of Niagara Falls Power Co.—In March, 1886, Charles B. Gaskill and seven associates organized the Niagara Hydraulic Tunnel, Power & Sewer Co. which planned to develop power by means of deep wheel pits and a tunnel. The capital stock was \$200,000, with power to increase it to \$3,000,000. The engineer was Thomas Evershed, division engineer of the western division of the Erie Canal. The original scheme devised by Mr. Evershed, was to dig a series of inlet canals at right angles to the shore of the Niagara River above Port Day, and beneath the inner ends of these construct a tailrace tunnel running parallel with the shore and discharging into the Maid-of-the-Mist Pool. Penstocks were to conduct the water down from the inlets to the turbines which were to discharge into the tunnel. Somewhat later it was decided to have only two river connections, one behind Connors Island, and the other behind Grass Island, the inner ends of these inlets being connected by a canal parallel to the river and adjacent to the south side of Buffalo Avenue. The inlets and canal were to form a ship canal or harbor. The tunnel was to parallel the canal along its south side, being sufficiently below to provide a developable head of water of 140 feet. The intent was to plan works which ultimately might develop 100,000 horsepower. Under these limiting conditions, and with such efficiencies of hydraulic turbines as were then obtained, this would require between 8,000 and 9,000 cubic feet of water per second, and it appears that the tunnel was designed with such slopes and cross-section as to discharge 8,600 cubic feet per second. A railroad was to parallel the canal, and factory sites were to have transportation facilities both by water and by land. The mills were to take water

from either side of the canal, drop it through their wheels, and discharge it into the tailrace tunnel.

A little later the idea of a central power station, from which power would be transmitted to factories along the canal, was introduced. At first the company found it difficult to interest capital in the concern, but by 1889, chiefly through the efforts of Mr. William B. Rankine, funds had been procured and the company was prepared to begin operations. The name of the company was changed to the Niagara Falls Power Co. Dr. Coleman Sellers was retained as consulting engineer and Clemens Herschel as hydraulic engineer. An auxiliary company—the Cataract Construction Co.—was organized and given a contract for a wheel pit and tunnel. This contract was let April 1, 1890, and work was begun in October of the same year.

Although work had started on the tunnel and wheel pit, the design of the plant was still unsettled in many essential points. Turbines of unprecedented size and power, acting under an unusually high head, had to be designed and built. Above all, the method of distributing the power was yet to be decided upon and the necessary apparatus designed. To determine these important points an "International Niagara Commission" was established in London, empowered to consider competitive plans and award \$22,000 in prizes. The members of the commission were: Sir William Thompson (afterwards Lord Kelvin), chairman, English; Prof. Cawthorn Unwin, secretary, English; Dr. Coleman Sellers, American; Lieut. Col. Theodore Turretini, Swiss; Prof. E. Mascart, French.

This commission, composed of some of the most eminent engineers of the time, made investigations in England, Switzerland, France, and Italy, and considered 20 competitive plans submitted to it. Its studies, which were devoted mainly to the subject of water wheels and their hydraulic accessories, resulted in the adoption of the turbine designs of Messrs. Feasch & Piccard, of Geneva. The turbines provided in the accepted design were of the Fourneyron type, twin runner without draft tubes, and rated at 5,500 horsepower each.

They were built by the I. P. Morris Co., of Philadelphia. The method of transmitting the power still remained to be settled. Three methods were considered, rope drive, pneumatic, and electric. Notable rope-drive installations were investigated. As late as 1892 the pneumatic transmission was receiving favorable consideration. Finally it was decided to use electric power, although electric generators of the size required were quite without precedent. In 1891 the power company invited competitive plans and estimates for the development of its electric power and for its transmission, both locally and to Buffalo. A very careful consideration of proposed installations led it to adopt a two-phase alternating current generator producing electric energy at about 2,000 volts, with a frequency of 25 cycles per second. This was perhaps the most important of the pioneer developments involving the use of alternating current and long-distance transmission, and its adoption involved a great deal of courage in view of the criticism of prominent engineers. The generators were designed by Prof. George Forbes, of London, the company's electrical engineer. They were of the external revolving field type. They were built by the Westinghouse Electric & Manufacturing Co., of Pittsburgh.

By August, 1895, the installation of three units had been completed and power was delivered to the Pittsburgh Reduction Co., for the manufacture of aluminum. A little more than a year later power was being delivered in Buffalo. The construction of this first power house was continued until in May, 1900, the tenth unit was put in service, marking the completion of plant No. 1. Three months before this, work had been commenced on the construction of a second plant on the other side of the canal, which followed the general lines of No. 1. The turbines, of the same capacity, were designed by the Escher Wyss Co., of Zurich, and were built and installed by the I. P. Morris Co. They were of the Francis type, inward flow, with single runners and double-draft tubes. The generators were built by the General Electric Co. Six generators are of the same type as those in plant No. 1. The other five have internal revolving fields. The first unit of this plant was put in operation in October, 1902, and the last one in March, 1904. About the year 1910 the turbines in plant No. 1 were replaced by new ones designed by the company's engineer, and built by the Bethlehem Steel Co. They are vertical-shaft Francis turbines with single runners and single-draft tubes.

Present plant of Niagara Falls Power Co.—Plate No. 31 shows the general layout of the Niagara Falls Power Co.'s plant. The canal makes an angle of about 125° with the current of the river. It is located just below Grass Island and is 1,200 feet long. Its width varies from about 200 feet at the entrance to 120 feet at the northeast end. The depth of water at ordinary stages is about 12 feet. Not far below the entrance a branch canal leads northwesterly to the International Paper Co. This tenant of the power company has until recently received water, not electric power, and this has been discharged through a branch tunnel into the main tunnel of the Niagara Falls Power Co. Along the northeast end of the northwest side of the canal stands plant No. 1. The building, designed by Stanford White, is a handsome structure of dark gray limestone, about 75 feet wide and 460 feet long. It contains ten 5,000-horsepower units. Plant No. 2 is a similar structure on the opposite side of the canal about midway of its length. It is about 580 by 100 feet and contains eleven 5,000-horsepower units. The water from the canal enters through arched openings in the front wall of the building into a fore bay inside. Here it enters the penstocks, $7\frac{1}{2}$ feet in diameter, which conduct it down into the wheel pit. Each penstock is provided with a motor-driven headgate. It is understood that the racks which formerly protected the entrance to the penstocks are no longer in use. The wheel pits are vertical trenches cut in the solid rock. They are about $17\frac{1}{2}$ feet wide and $177\frac{1}{2}$ feet deep. The wheel pit in plant No. 1 is $424\frac{1}{2}$ feet long; that in No. 2 is 461 feet. At the bottom of the penstocks the water makes a right-angled turn and enters the turbines about 134 feet below the powerhouse floor. The speed of the turbines is regulated at 250 revolutions per minute by cylinder gates operated by oil pressure governors on the generator floor. The draft tubes discharge the water into a tailrace formed by the bottom of the wheel pit. From the bottom of the northeast end of each wheel pit the water enters a tailrace tunnel. The tunnel from No. 1 intersects that from No. 2 at an angle of 60° . From this intersection the length of tunnel to plant No. 1 is about 50 feet and to No. 2 is about 600 feet, each branch swinging around a curve through an angle of

almost 122° . The tunnel runs in a straight line from this intersection to its outlet just downstream from the upper steel arch bridge, a distance of about 7,000 feet. It is of horseshoe shaped cross-section 21 feet high and 18 feet 10 inches wide, with a cross-sectional area of 335 square feet. It is lined with brick. The bottom of the tunnel at the wheel pits is about 44 feet above the level of the river at the outfall. The slope is 4 feet per thousand for the first one-third of the length and 7 feet per 1,000 from there to a point 95 feet from the outfall. Thence it drops $10\frac{1}{2}$ feet in an ogee curve, and the open end is about half submerged at normal stages. This last 85-foot length of the tunnel is lined with steel plates.

The portal is of granite masonry founded on a hard sandstone ledge. The velocities through the tunnel are extremely high. When all machines are operating at full load the velocity is about 30 feet per second in the tunnel and about 45 feet per second at the outfall, which latter figure is equivalent to 30 miles per hour and is twice as great as the highest velocity in the rapids above the crest of the Horseshoe Falls. About one-third of the available energy of the water is used up in forcing itself through the tunnel at this high velocity, and this loss of power forms the chief reason for the low overall efficiency of the plant.

The power developed by the turbines is transmitted to the generator floor by large vertical steel shafts. These are made of steel tubing 38 inches in diameter and three-eighths inch thick, except at the bearings, where they are solid and are 11 inches in diameter. There are three bearings between the turbines and the generator floor, each accessible by a deck in the pit. The weight of each shaft with the moving parts of the turbine and generator is about 100 tons. In powerhouse No. 2 this weight is partly balanced by hydrostatic pressure on a flange inside the turbine case. The rest of the weight, and the full weight of the moving part in Plant 1 is supported by oil pressure thrust bearings located below the generators, on what is called the "thrust deck." The generators are of the umbrella type and are rated at 3,750 kilovolt-amperes each. They are operated at 250 revolutions per minute, and generate two-phase alternating current at 25 cycles per second, 2,200 volts. There are four exciters in each plant, located in small chambers cut in the rock near the bottom of the wheel pits, and driven by Pelton wheels. Two main switchboards are installed in plant No. 1, each controlling and distributing the output of five generators. The main generator and feeder switches are operated pneumatically. In power house No. 2 the entire output of the plant is controlled and distributed from a single operating switchboard, switches being operated electrically.

Plate No. 32 shows a typical cross-section through powerhouse No. 2.

For the operation of near-by plants, power is transmitted at 2,200 volts, two phase. For the more distant plants in the Niagara Falls district it is stepped up to 11,000 volts, and changed to three phase. Power is transmitted to Buffalo and other cities at 22,000 volts, three phase. The farthest transmission is to Olcott, a distance of about 36 miles. The step-up transformer station is located directly across the canal from plant No. 1. It contains 16 air-blast transformers of 1,250 horsepower each, which change the generated energy from 2,200 volts, two phase, to 22,000 volts, three phase; and 16 oil-in-

sulated, water-cooled transformers of 2,500 horsepower each, which change the characteristics of the electric energy generated from two phase, 2,200 volts, to three phase at either 11,000 or 22,000 volts, as may be required.

Tests by the United States Lake Survey show that about 10.8 horsepower are developed per cubic foot per second when 21 units are operating at their rated capacity of 5,000 horsepower each, the total diversion being 9,700 cubic feet per second. This gives an over-all efficiency of 43½ per cent. With a smaller load the tail-water does not stand so high in the wheel pit, and the efficiency is greater. The company ordinarily operates 21 units to generate about 100,000 horsepower, using 9,450 cubic feet per second. This is 10.6 horsepower per cubic foot per second and represents an efficiency of 42½ per cent.

Photographs Nos. 155 to 168 give an idea of the appearance of the principal elements of the plant during construction and after completion. A brief explanation accompanies each view.

In regard to the steep slope and small size of tunnel, with the consequent great loss in over-all efficiency, a few words of explanation seem pertinent. At the time of the inception of this project there were very few places in the world where water power had been developed under a head of 100 feet or more, and none where the quantity of water used under such a head was large. The Hydraulic Power Co. then contemplated developments of only 90 to 100 feet of head. The 140 feet provided in the plans of this new development therefore indicated a step forward into almost unknown realms of engineering. The ultimate proposed development of 100,000 horsepower, which it was expected would be used night and day, amounted in horsepower-hours to about five times the water power developed in Lowell, Lawrence, and Holyoke combined. These were cities of the first magnitude as regards water-power development, and a project contemplating a production of 100,000 horsepower was stupendous. At that time the ultimate development planned by the Hydraulic Power Co. was 20,000 horsepower. It was not expected that the 100,000 horsepower limit would be reached for many years, but, when it was, the total diversion from Niagara River would be only 8,600 cubic feet per second or thereabouts, and this seemed such an insignificant fraction of the river flow that apparently nobody foresaw a time when the supply would be limited or a more efficient use of the diversion considered essential.

As already noted under the preceding description of the Hydraulic Power Co., the three companies, namely, the Niagara Falls Power Co., Hydraulic Power Co., and Cliff Electrical Distributing Co., combined under the name of the Niagara Falls Power Co., on October 31, 1918. At the time of the merger the outstanding stock of the Niagara Falls Power Co., was \$5,757,700 and the outstanding bonds \$18,226,000.

At the time of the merger the Niagara Falls Power Co. possessed a right granted by the State to develop 200,000 horsepower. A brief history of Federal legislation in regard to diversions of water from Niagara River by this company, and of permits and supervision pertaining thereto, as well as quantities of diversions thereunder, is given in Section C of this report.

International Paper Co.—The International Paper Co. buys water power from the Niagara Falls Power Co. Its lease gives it the right to receive approximately 750 cubic feet per second of water from the

power company's canal and discharge it into the tailrace tunnel. Water has until recently been taken from the intake of the Niagara Falls Power Co. through a canal about 30 feet wide, 10½ feet deep, and 385 feet long. From the end of the canal the water descended into the wheel pit in a penstock 12 feet in diameter, from which it was supplied through short branch pipes to six wheels. These were Jonval turbines of 1,300 horsepower each. From them the water went through a tailrace tunnel of circular section 660 feet long and 7 feet in diameter, entering the power company's main tunnel at an abrupt angle 835 feet downstream from the junction of the two main tunnel branches. Little is known of the efficiency of this installation, but it was probably somewhat less than that of the Niagara Falls Power Co. Recently this power plant has been dismantled and removed. It is understood that the rights have been retained and that turbines are under construction for a new installation.

3. PROPOSED PLANT USING ENTIRE DIVERSION AND TOTAL HEAD IN ONE STAGE.

General remarks.—Three types of installation for utilizing in one stage the entire diversion and total head have been suggested. The first provides for a power house somewhere on the upper river, with water wheels installed in a deep pit, the water flowing from the wheels to the lower river through a tailrace tunnel. The second proposition calls for an intake on the upper river and a tunnel from it to a power house in the Gorge of the lower river. The third is similar to the second except that the tunnel is replaced by an open canal. Plans providing a combination of two of these ideas are possible, but seem to offer no advantages. Outline plans and estimates have been made for each of these three projects.

Tailrace tunnel proposition.—An economic study of the location of this project showed that to get the greatest return on the investment the power house should be located on the shoal just upstream from Grass Island and that the outfall of the tunnel should be at or not far downstream from the Devils Hole. Plate No. 33 shows the general layout of the project with the outfall near Riverdale Cemetery. The general design of the power house is shown on plate No. 34. A channel 600 feet wide is to be dredged in the river from the deep water half a mile upstream. Along the face of the proposed power house the channel is 25 feet deep at low water. The bottom of the channel slopes transversely so that the depth on the south side is but 10 feet. For half a mile downstream from the power house all shoal spots are dredged to a depth of 10 feet at low water. The face of the power house extends along the deep side of this dredged cut for about 1,100 feet. It contains 34 arched openings each with an area of 329 square feet. The crowns of the arches are each 11 feet below low water. Four feet above the crowns a concrete shelf projects 5 feet from the wall along the whole front. With this construction it is expected that there will always be a considerable current past the power house and that very little ice will pass under the arches.

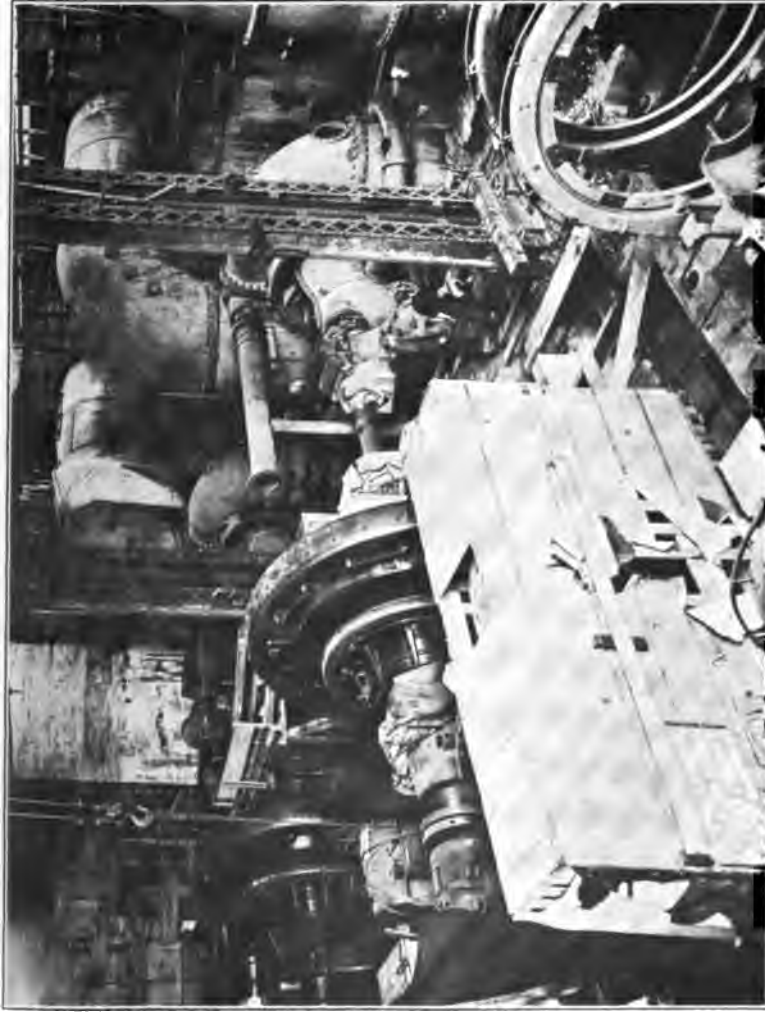
Each pair of submerged arches serves one turbine. Passing through any arch the water enters a small fore bay, 24 by 29 feet in horizontal dimensions. Just inward from the arch are slots in which stop logs may be placed whenever it is desired to drain the fore bay



Photograph No. 152.—STATION 3, TURBINE ROOM, HYDRAULIC POWER CO.



Photograph No. 153. STATION 3. GENERATOR ROOM. HYDRAULIC POWER CO.



Photograph No. 154.—STATION 3, UNDER CONSTRUCTION HYDRAULIC POWER CO.



Photograph No. 155.—MAIN TUNNEL, UNDER CONSTRUCTION. NIAGARA FALLS
POWER CO.



Photograph No. 156.—WHEEL PIT OF POWER HOUSE NO. 2, UNDER CONSTRUCTION. NIAGARA FALLS POWER CO.



Photograph No. 157.—WHEEL PIT OF POWER HOUSE NO. 2, UNDER CONSTRUCTION, NIAGARA FALLS POWER CO.



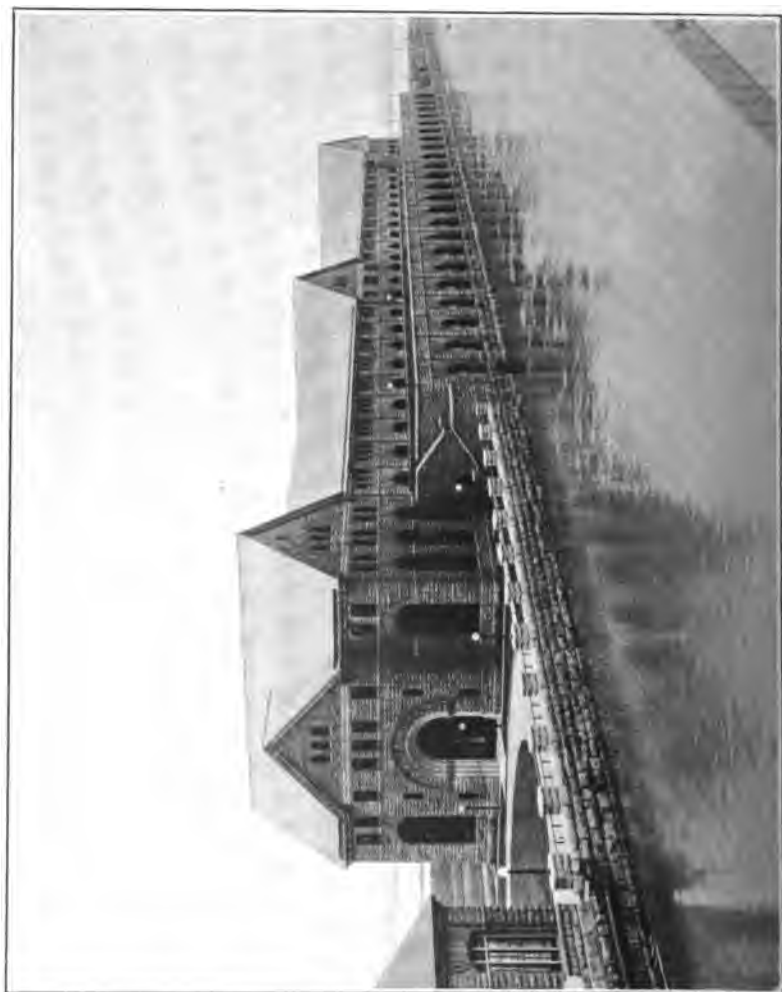
Photograph No. 158.—WHEEL PIT OF POWER HOUSE NO. 2. UNDER CONSTRUCTION. NIAGARA FALLS POWER CO.



Photograph No. 159. - GENERAL VIEW OF PLANT. NIAGARA FALLS POWER CO.



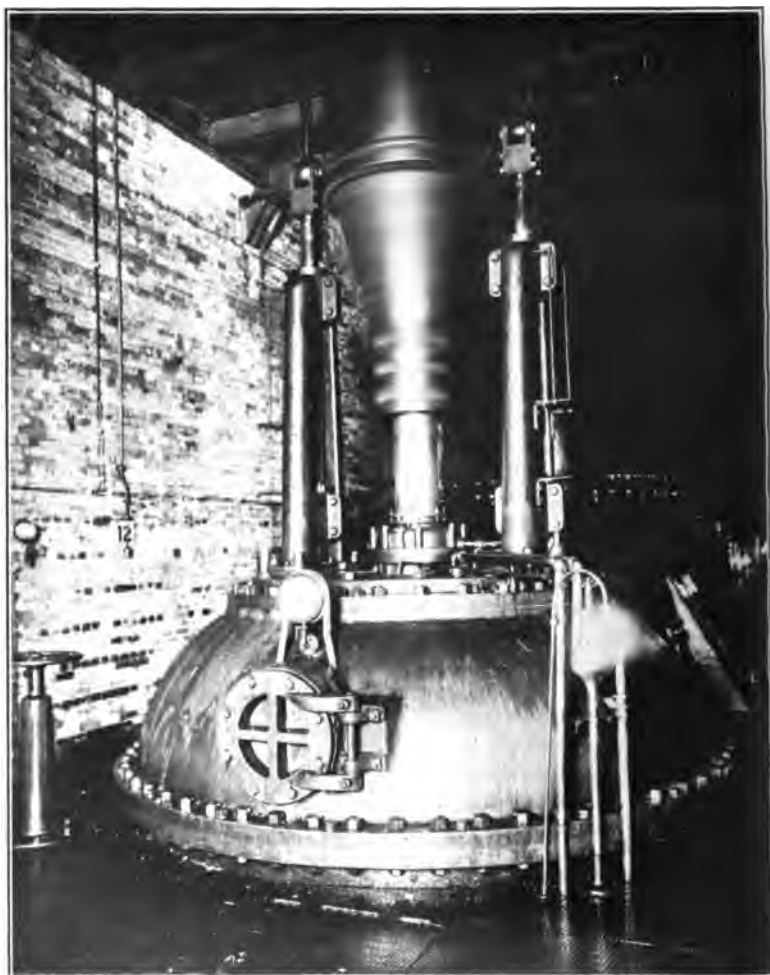
Photograph No. 160.—INTAKE CANAL. NIAGARA FALLS POWER CO.



Photograph No. 161.—POWER HOUSE NO. 2, NIAGARA FALLS POWER CO.



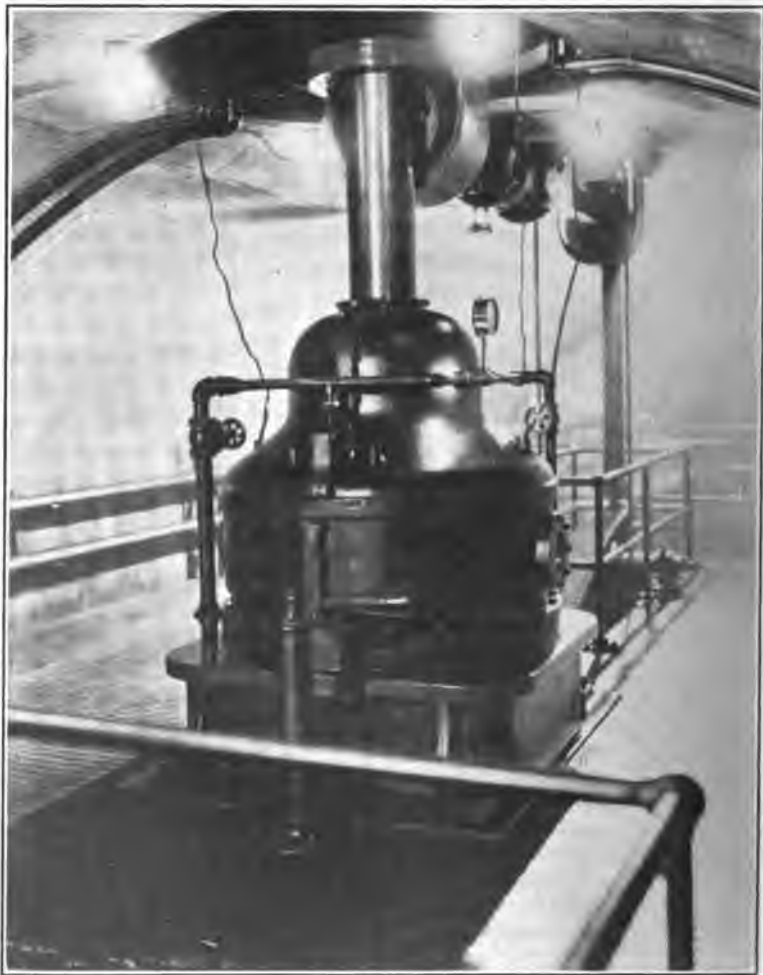
Photograph No. 162.—RACK ROOM OF POWER HOUSE NO. 2. NIAGARA FALLS POWER CO.



Photograph No. 163.—TURBINE IN POWER HOUSE NO. 2. NIAGARA FALLS
POWER CO.



Photograph No. 164.—MAIN TUNNEL OUTFALL. NIAGARA FALLS POWER CO.



Photograph No. 165.—THRUST BEARING. NIAGARA FALLS POWER CO.



Photograph No. 166.—GENERATORS IN POWER HOUSE NO. 1, NIAGARA FALLS POWER CO.



Photograph No. 167. GENERATOR ROOM, POWER HOUSE NO. 2. NIAGARA FALLS POWER CO.

for repairs. Beyond these is a set of racks to prevent weeds and trash from entering the penstocks. A traveling crane, running the full length of the building over the fore bays, provides for handling the heavy rakes used in clearing the racks. From the north side of each fore bay the water flows through a bellmouth entrance into a steel penstock, 10 feet in diameter. Each penstock is provided with a gate, a by-pass, and air vent.

The water wheels and generators are in a deep pit. Each generator rests at the bottom of an open shaft, 25 feet in diameter, which descends to the generator floor at elevation 292. For 18 feet above this floor the shaft is enlarged to 30 feet. The generators are of the vertical-shaft type with internal revolving field. On top of each one is a direct-connected exciter. The generators are rated at 27,000 kilowatts, continuous maximum output at 90 per cent power factor, at 12,000 volts, 3 phase, 25 cycles per second. Their speed is about 221 revolutions per minute. A longitudinal passage or tunnel, parallel to the main wheel pit, at the elevation of the generator floor, is connected to each little generator room by a short lateral passage.

Each turbine is fed by two penstocks. Between each pair of generator pits is a pit containing two penstocks together with the electric conductors, ventilating ducts, and other apparatus. By means of this arrangement it will be possible to conduct cool air down the penstock pits and through passages to the generators—the heated air from the generators rising vertically in the generator pits. At the bottom of each penstock pit are two synchronous relief valves, one on each penstock. Stairs from the passage lead to a governor room under each generator and from there passages lead to the bottom of the penstock shafts. The penstocks turn at right angles to enter the turbines, whose centers are at elevation 265. The turbines are of the vertical shaft, single-runner type, having inward and downward flow, with double scroll cases, and single draft tubes. They are rated at 37,000 horsepower maximum. Each is direct connected to its generator, and the complete rotating part is supported on a Kingsbury thrust bearing. Beneath the turbines is a tailrace into which the draft tubes discharge. The top of this tailrace is at elevation 248. The cross section is of horseshoe shape, 20 feet wide, 20 feet high at the upstream end, and 48 feet wide and high at the down stream end.

The building above the wheel pit contains a switchboard, oil switches, busses, cranes, and other machinery necessary to the operation of the plant. Its floor is at elevation 567. Two elevators connect it with the passage at the generator level. A spur track connection between the power house and the Niagara Junction Railway is provided.

The tailrace tunnel is of horseshoe section, 48 feet high and 48 feet wide, with a cross-sectional area of 1,970 square feet. It is lined with concrete. Thickness of lining and cross-sectional proportions are in accordance with the standards described in Part E-1. Starting from the west end of the power house it makes a curve of 800-foot radius, 1,280 feet long. Thence it runs straight to the portal below the Riverdale Cemetery, except for a slight curve near the lower end to prevent it reaching the river at too acute an angle. The total length is 26,000 feet. For a considerable distance the location

is wholly or partially under Seventeenth Street. Its profile is level throughout with the invert at elevation 200. When taking the full diversion of 20,000 cubic feet per second the mean velocity in the tunnel will be 10.15 feet per second.

It is planned to deposit the spoil from the wheel pit and tunnel along the shore of Niagara River, between Grass Island and Conners Island, and south of Conners Island, as shown on the map, plate No. 33. This will form about 210 acres of valuable land for factory sites. Adjacent vacant land now has an assessed value of \$5,000 per acre.

Taking "Kutter's N" as 0.013, the loss of head in the tunnel will be 9 feet. The loss of head at the intake through the racks in the bellmouths and penstocks, in the tapering section of the tunnel, and at the tunnel outfall is estimated at 4.5 feet. Total loss of head is 13.5 feet. Mean elevation of headwater is 562.5. Mean elevation of tailwater is 250. Gross head is the difference or 312.5 feet. Net head is 312.5 minus 13.5 or 299 feet. Assuming the combined efficiency of the turbine and generator to be 86 per cent, the total power produced by 20,000 cubic feet per second is 584,000 horsepower, which is 29.2 horsepower per cubic foot per second. This is equivalent to an over-all efficiency of 82.4 per cent.

Table No. 32 is a summary of an estimate of the cost of this project. The total is \$52,220,000, which amounts to \$89.40 per horsepower. Estimated time of development is three years for first power, and five years for completion.

TABLE No. 32.—*Tailrace tunnel proposition—Summary of estimate of construction cost.*

Item.	Quantity.	Unit price.	Amount.	Total.
Dredging in river, hardpan.....cubic yards..	379,400	\$1.25	\$474,000.00	
Total river work.....				\$474,000.00
Cofferdam, D-6 feet.....linear feet..	2,600	14.40	337,000.00	
Rock excavation.....cubic yards..	411,000	5.00	2,055,000.00	
Plain concrete.....do.....	177,210	12.00	2,127,000.00	
Reinforced concrete.....do.....	4,470	25.00	112,000.00	
Building:				
Main portion.....square feet..	55,800	15.00	837,000.00	
Over racks and fore bay.....do.....	51,100	12.00	613,000.00	
Racks.....pounds..	1,142,000	.10	114,000.00	
Stop logs, steel.....do.....	148,000	.10	15,000.00	
Total power house.....				5,910,000.00
Turbines and generators.....horsepower..	629,000	14.15	8,900,000.00	
Erection and accessories.....do.....	629,000	3.30	2,076,000.00	
Steel penstocks.....pounds..	10,418,000	.10	1,042,000.00	
Penstock gates.....	34	2,500.00	85,000.00	
Synchronous relief valves.....	34	6,000.00	204,000.00	
Total equipment.....				12,307,000.00
Tailrace tunnel, 48 feet diameter.....linear feet..	26,000	735.00	19,110,000.00	
Portal, gorge route tracks, etc.....			100,000.00	
Tunnel shafts, 25 feet square.....cubic yards..	31,710	12.00	381,000.00	
Total tunnel.....				19,591,000.00
Real estate.....				44,000.00
Summation.....				38,326,000.00
Contingencies, 15 per cent of \$38,326,000.....				5,749,000.00
Engineering and superintendence, 10 per cent of \$38,326,000.....				3,833,000.00
Summation.....				47,908,000.00
Construction interest, 9 per cent of \$47,908,000.....				4,312,000.00
Construction cost.....				52,220,000.00
Cost per horsepower for 584,000 horsepower.....				\$89.40

Pressure tunnel proposition.—The economic location of this project is determined by the same factors as the preceding one, and a study of the limiting conditions leads to the choice of the same location. The intake is on the shoal just upstream from Grass Island, and the power house is in the Gorge below the Riverdale Cemetery. The general plan of this project is shown on plate No. 33, and the details on plates Nos. 35, 36, and 37. The approach channel above Grass Island is the same as for the tailrace tunnel, and the arched wall of the intake stands just where the arched wall of the power house stands in the preceding proposition. The arrangement of arches, with their crowns 11 feet below the water surface and a 5-foot concrete shelf above them, is the same as before, but the area of each opening is 292 square feet, and there are 30 openings. Passing under the arches the water enters a fore bay 22 feet wide and 750 feet long. On the north side of the fore bay are the racks, in 30 panels, each 21 feet wide and 26 feet deep below low water. Each panel of racks is set between concrete piers, 4 feet thick, with provision for placing stop logs in front of the racks. Behind the racks are vertical steel gates, motor driven, each capable of closing the opening of one bay, which is 21 feet wide in the clear and 31 feet high to the gatehouse floor. A building, 60 feet wide and 800 feet long, covers the fore bay and racks and contains a crane for raking and handling racks. Behind the rack house the water goes between converging concrete walls to a vertical shaft, 50 feet in diameter, through which it descends into the tunnel. The bottom between the concrete walls has a curved profile designed to preserve a nearly constant velocity of about 5 feet per second to prevent freezing in wintertime. The bottom lining is to be bonded to the underlying rock, which latter is to be grouted in so far as necessary to provide against leakage and uplift when the basin is empty. Provision is to be made for draining water into the tunnel from the south portion of the intake basin when the gates are closed. A railroad spur track will extend on a fill to the gatehouse from the Niagara Junction Railway.

The tunnel is identical in cross section with that of the previous proposition. It is about 25,000 feet long, and at its upstream end connects with the downtake shaft by a vertical curve. The elevation of the tunnel invert at this end is 400, while at the lower end it is 275. Near the lower end of the tunnel a circular tunnel, 43 feet in diameter, branches off and rises to a "differential surge tank" located between the top of the cliff and the railroad, just south of the abandoned quarry. The tank is of concrete, 124 feet in diameter, and rises about 90 feet above the ground surface. The spoil from the tunnel is to be disposed of the same as in the tailrace tunnel scheme.

The power house is a masonry building at the foot of the cliff, after the style of station 3 of the Hydraulic Power Co. It is about 870 feet long and 85 feet wide. Seventeen circular penstock tunnels, 12 feet in diameter and concrete lined, branch off from the lower end of the tunnel at an angle of about 45 degrees. In continuation of these, steel penstocks, 12 feet in diameter, enter the substructure of the power house. A penstock valve in each one serves as a gate. The turbines and generators are identical in capacity and other characteristics with those provided in the tailrace tunnel

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proposition, except that the scroll cases are single, and each one is fed by a single penstock. The centers of the turbines are at elevation 265. The generator floor is at elevation 280. The draft tubes discharge into tailraces leading directly into the lower river. The busses, oil switches, and other necessary auxiliaries, are located along the eastern part of the power house.

The mean elevation of the headwater and tail-water is the same as for the tailrace tunnel project, giving a gross head of 312.5 feet. The tunnel is shorter and the loss of head in it is estimated at 8.5 feet. The loss in the intake, together with penstock losses and other minor losses, is estimated at 2.75 feet. Total loss of head is 11.25 feet. Net head is 301.3 feet. Assuming the combined efficiency of turbine and generator as 86 per cent, the total power produced by 20,000 cubic feet per second is 588,000 horsepower, which is 29.4 horsepower per cubic foot per second. This is equivalent to an overall efficiency of 82.9 per cent.

Table No. 33 is a summary of an estimate of cost of this project. The total is \$50,803,000, which amounts to \$86.40 per horsepower. Estimated time of development is 3 years for first power and 5 years for completion.

TABLE NO. 33.—*Pressure tunnel proposition—Summary of estimate of construction cost.*

Item.	Quantity.	Unit price.	Amount.	Total.
Dredging in river, hardpan.....cubic yards..	385,700	\$1. 25	\$482,000. 00	
Total river work.....				\$482,000. 00
Cofferdam, D-5 feet.....linear feet.....	2,200	10. 00	22,000. 00	
Rock excavation.....cubic yards.....	94,500	3. 50	331,000. 00	
Plain concrete.....do.....	26,200	12. 00	315,000. 00	
Reinforced concrete.....do.....	2,320	25. 00	58,000. 00	
Racks.....pounds.....	880,000	. 10	88,000. 00	
Stop logs (steel).....do.....	102,000	. 10	10,000. 00	
Gates.....	30	19,000. 00	570,000. 00	
Building.....square feet.....	48,000	12. 00	576,000. 00	
Total intake.....				1,970,000. 00
Downtake shaft, 50 feet diameter.....linear feet.....	100	1,185. 00	118,000. 00	
Main tunnel, 48 feet diameter.....do.....	26,000	735. 00	18,375,000. 00	
Tapering tunnel, 30 feet mean diameter.....do.....	630	403. 00	254,000. 00	
Penstock tunnels, 12 feet diameter.....do.....	2,380	125. 00	298,000. 00	
Shafts, 25 feet square.....cubic yards.....	20,900	12. 00	251,000. 00	
Total tunnels.....				19,296,000. 00
Rock excavation.....cubic yards.....	14,300	3. 00	43,000. 00	
Plain concrete.....do.....	1,670	15. 00	25,000. 00	
Reinforced concrete:				
3½ per cent steel.....do.....	3,310	50. 00	166,000. 00	
3 per cent steel.....do.....	970	45. 00	44,000. 00	
Tunnel, 43 feet diameter circular.....linear feet.....	460	918. 00	422,000. 00	
Roof and incidental.....			25,000. 00	
Total surge tank.....				725,000. 00
Rock excavation.....cubic yards.....	214,900	3. 50	752,000. 00	
Cofferdam, D-15.....linear feet.....	950	90. 00	86,000. 00	
Plain concrete.....cubic yards.....	40,950	12. 00	491,000. 00	
Reinforced concrete.....do.....	1,290	25. 00	32,000. 00	
Building.....square feet.....	74,000	15. 00	1,110,000. 00	
Rebuilding trolley track.....			6,000. 00	
Total power house.....				2,471,000. 00
Turbines and generators.....horsepower.....	629,000	14. 15	8,900,000. 00	
Erection and accessories.....do.....	629,000	3. 30	2,076,000. 00	
Penstocks, steel.....pounds.....	1,886,000	. 10	189,000. 00	
Penstock valves.....	17	63,000. 00	1,071,000. 00	
Total equipment.....				12,236,000. 00
Real estate.....				100,000. 00
Summation.....				37,286,000. 00

TABLE No. 33.—*Pressure tunnel proposition—Summary of estimate of construction cost—Continued.*

Item.	Quantity.	Unit price.	Amount.	Total.
Contingencies, 15 per cent of \$37,286,000.....				\$5,593,000. 00
Engineering and superintendence, 10 per cent of \$37,286,000.....				3,729,000. 00
Summation.....				46,608,000. 00
Construction interest, 9 per cent of \$46,608,000.....				4,195,000. 00
Construction cost.....				50,803,000. 00
Cost per horsepower for 588,000 horsepower is.....				86. 40

On plate No. 33 there is shown an alternative location of the tunnel under Sugar Street, with a boat-shaped intake near the middle of the river, abreast the head of Conners Island. Details of the outline design of this intake and connection are shown on plate No. 38. It was thought there was an advantage in having the tunnel under Sugar Street, because the right of way might prove cheaper and because a construction railway might be laid along this straight street connecting all the tunnel shafts with spoil bank and so lessen the cost of spoil disposal. It seemed to be advantageous also to have the intake in deeper water and farther from shore and with a broad expanse of water on both sides of it moving with moderate velocity in order to insure sufficient freedom from ice troubles. The disadvantages are the greater length of tunnel, more costly intake, and increased amount of tunnel work under the river bed. After some consideration it was decided that the disadvantages probably outweighed the advantages, and the estimate for the alternative location was not completed.

It might be noted that it has been proposed to place the head gates at the narrow part of the intake near the tunnel entrance, using only three or four gates, which would necessarily be of large size. It is quite possible that such a design might be somewhat less expensive than the one presented and that the flow of water to the tunnel could be shut off more quickly by such gates.

Power-canal proposition.—In designing the project for an open canal from the upper river to the lower part of the Gorge very extensive studies were made to determine the most economical location for the canal. The topographic map, which constitutes plates Nos. 13 and 14, was used. This shows land contours with 2-foot interval over the whole area between Sugar Street and Military Road, as well as along Bloody Run, and also shows about 120 rock soundings in this area. On this map 36 routes were laid out. Profiles were drawn and the relative economy of the different routes determined. The cost of bridges and real estate and the annual value of the power lost were included in the study, as well as the cost of rock excavation, earth excavation, and concrete. The 36 routes were well spaced over the whole area between Sugar Street and Military Road and involved intakes at five different points between Gill Island and the head of the Little River behind Cayuga Island, as well as three power-house sites in the Gorge, namely, at the Devil's Hole, Riverdale Cemetery, and just above Fish Creek.

The adopted location starts from an intake in the river just south of Conners Island and runs due north (along the meridian of 79°

01' W. longitude). As it nears the Lockport branch of the New York Central Railroad it bends to the west on a curve of about 2,000 feet radius and crosses the tracks just east of the railroad yard. Thence it runs approximately north 30° west to a fore bay at the top of the cliff north of the Niagara, Lockport & Ontario Power Co.'s transmission line and west of the Rome, Watertown & Ogdensburg branch of the New York Central Railroad. The canal begins at the north end of the intake almost exactly on the present shore line of the mainland north of Connors Island and ends at the south end of the fore bay, where the west fence of the railroad passes under the center of the transmission line. The length between these points is 24,950 feet. The canal bottom is given a slope of 0.35 foot per thousand feet, or 1.848 feet per mile.

Studies were also made of the most economical cross section. The wetted section adopted is 56 feet wide and 56 feet deep at mean stage. The sides are channeled and the bottom left as smooth as is practicable in dry-rock excavation. It was decided that it was preferable not to line the bottom or sides with concrete, but to enlarge the cross section sufficiently to provide equivalent capacity. For hydraulic computations the value of "Kutters n" was taken at 0.028. When the flow is 20,000 cubic feet per second the slope of the water surface is 0.000288 at mean stage and 0.000311 at standard low water. Where the highest stage of water in the canal brings the water surface above the rock surface reinforced concrete retaining walls are built on each side of the canal. This condition obtains only at the southerly end of the route. The exposed sides of the earth cut are given a 1 on 2 slope. On one side a 10-foot berm on the rock surface prevents earth from sliding into the canal. On the other side a 25-foot berm is provided to leave room for a roadway and transmission line.

Starting at deep water near the middle of the Tonawanda channel of Niagara River, an approach channel 1,875 feet long is dredged leading to the intake. This channel is 700 feet wide by 12 feet deep at the upper end and 185 feet wide by 32 feet deep at the lower end, at the west end of the intake arches. The intake-arch wall is a massive concrete structure 425 feet long and 25 feet thick, with its top 6.2 feet above mean stage. An ice-diverting shelf was considered unnecessary, partly because of the location and partly because of the ice run at the power house. The intake wall is pierced by 16 arches, each of 20-foot span, 15 feet high at the springings and 20 feet at the crown. The crowns are 12 feet below standard low water. The maximum velocity through these arches will be 3.3 feet per second. The arches are about 1,200 feet south of Connors Island.

Behind the arches is the bellmouth approach to the main canal. It is 2,000 feet long, 400 feet wide at one end and 56 feet wide at the other. The depth of water varies from 23 to 56 feet in such a manner as to give a uniform acceleration of velocity from 1.50 to 6.38 feet per second. On each side is a massive retaining wall rising to elevation 570.

At the downstream end of the canal is the fore bay. Starting with a wetted section 56 feet by 56 feet, it expands in the first 500 feet to a section 130 feet wide by 40 feet deep, and at the same time makes a bend of about 30° to the right, the velocity being uniformly retarded from 6.38 feet to 5.95 feet per second. Then for 900 feet

along the face of the rack house it maintains the same depth, but narrows down to a width of 25 feet.

The rack house is a building 950 feet long and 42 feet wide situated on the west side of the fore bay. The central 850 feet, the rack house proper, is divided into 34 bays by concrete piers 5 feet thick placed 25 feet center to center. Between each pair of piers is a rack structure. Entrance to each bay is provided by a submerged arched opening 13 feet high at the springings and 18 feet high in the center. The crown of the arch is 12 feet below mean stage at full load on plant. Just above the crowns of the arches runs a horizontal concrete "ice-diverting shelf" 5 feet wide. The tops of the piers and the main floor of the rack house are at elevation 576, well above the highest possible surge, account being taken of the spillways provided. The house has the usual crane, rack-raking equipment, stop logs, etc. Every two bays supply water to one 15-foot circular penstock tunnel, descending at an angle of 45° . The velocity is 1.75 feet per second through the submerged arches, 0.98 between the piers, and about 1.50 through the racks.

At each end of the rack house are two similar bays forming an ice run. They differ from the central bays in that their entrances are not obstructed by arches, and that, in place of racks, each bay contains a spillway with a gate sliding vertically in a recess in the concrete weir, and whose crest is movable between elevations 548 and 576. Each pair of gates serves one 15-foot circular ice-run tunnel discharging under the tracks of the Gorge Route Railway. It is estimated that at mean stage, with a flow of 20,000 cubic feet per second in the canal, the discharging capacity of the two ice runs will exceed 5,000 cubic feet per second. With the stage lowered by ice to 554, the capacity would still be about 3,000 cubic feet per second. When not lowered for ice sluicing it is intended that these gates be set at an elevation a few inches higher than the water at Connors Island. They will then serve as surge spillways in case of sudden shutdowns in the power house. Before a surge could reach the top of the fore-bay walls the spillways would be discharging nearly 8,000 cubic feet per second.

The penstock tunnels extend downward at an angle of 45° for about 280 feet; then, by a curve of 240 feet radius, become horizontal with center lines at elevation 265. This point is reached about 13 feet from the flange of the penstock valve in the east wall of the power house. The 45-foot length of tunnel next to the valve is 12 feet in diameter, and has a steel lining. The next 25-foot length away from the power house is lined with concrete only, and tapers from 12 feet to 15 feet in diameter. The remaining 412-foot length is 15 feet in diameter. The mean velocity is 6.66 feet per second in the 15-foot section and 10.42 in the 12-foot section.

The power house and equipment are practically the same as in the pressure-tunnel project, except that the center lines of penstocks and valves are at right angles to the building instead of being on a skew.

The gross head is 313.8 feet. The loss of head is estimated at 11 feet, of which $7\frac{1}{4}$ feet is in the canal itself. This gives a net head of 302.8 feet. With the use of 20,000 cubic feet per second at a combined turbine and generator efficiency of 86 per cent, the power out-

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put is 591,000 horsepower, which is 29.6 horsepower per cubic foot per second. This is equivalent to an over-all efficiency of 83 per cent.

Table No. 34 gives the summary of an estimate of the cost of this project. The total is \$43,579,000, which amounts to \$73.70 per horsepower. Estimated time of development is two and one-half years for first power and five years for completion.

TABLE No. 34.—*Power canal proposition—Summary of estimate of construction cost.*

Item.	Quantity.	Unit price.	Amount.	Total.
Dredging in river:				
Hardpan.....cubic yards..	191,300	\$1.25	\$239,000.00	
Rock.....do.....	103,700	6.50	674,000.00	
Total river work.....				\$913,000.00
Cofferdam, D=10.5 feet.....linear feet..	4,100	44.00	180,000.00	
Earth excavation.....cubic yards..	290,000	1.75	507,000.00	
Rock excavation.....do.....	229,000	3.50	802,000.00	
Backfill.....do.....	28,000	.45	13,000.00	
Plain concrete.....do.....	29,860	12.00	478,000.00	
Total intake.....				1,980,000.00
Earth excavation.....cubic yards..	1,934,000	.65	1,257,000.00	
Rock excavation.....do.....	3,469,500	2.25	7,806,000.00	
Backfill.....do.....	261,000	.45	118,000.00	
Concrete in reinforced walls.....do.....	25,800	15.00	387,000.00	
Reinforcing steel.....pounds..	1,666,000	.07	117,000.00	
Total canal.....				9,685,000.00
Total bridges.....				432,000.00
Earth excavation.....cubic yards..	69,000	1.25	86,000.00	
Rock excavation.....do.....	186,000	3.00	558,000.00	
Backfill.....do.....	11,200	.45	5,000.00	
Plain concrete.....do.....	10,000	12.00	120,000.00	
Total fore bay.....				770,000.00
Earth excavation.....cubic yards..	12,700	1.25	16,000.00	
Rock excavation.....do.....	44,000	3.00	132,000.00	
Backfill.....do.....	2,300	.45	1,000.00	
Plain concrete.....do.....	25,050	12.00	301,000.00	
Reinforced concrete.....do.....	3,050	25.00	76,000.00	
Building.....square feet..	40,000	12.00	480,000.00	
Racks.....pounds..	2,500,000	.10	250,000.00	
Ice run gates.....	4	17,000.00	68,000.00	
Stop logs, steel, for one penstock.....pounds..	288,000	.10	29,000.00	
By-passes.....	17	1,000.00	17,000.00	
Total rack house and ice run.....				1,370,000.00
Circular tunnels, 15 feet diameter.....linear feet..	8,134	156.00	1,269,000.00	
Tapering tunnels, 15 to 12 feet diameter.....do.....	425	154.00	65,600.00	
Circular tunnels, 12 feet diameter.....do.....	765	124.00	95,000.00	
Total penstock and ice run tunnels.....				1,429,000.00
Rock excavation.....cubic yards..	214,900	3.50	752,000.00	
Cofferdam, D=15.....linear feet..	950	90.00	86,000.00	
Plain, concrete.....cubic yards..	40,950	12.00	491,000.00	
Reinforced concrete.....do.....	1,290	25.00	32,000.00	
Building.....square feet..	74,000	15.00	1,110,000.00	
Rebuilding trolley track.....			6,000.00	
Total power house.....				2,477,000.00
Turbines and generators.....horsepower..	629,000	14.15	8,900,000.00	
Erection and accessories.....do.....	629,000	3.30	2,076,000.00	
Penstocks, steel.....pounds..	1,886,000	.10	189,000.00	
Johnson valves.....	17	63,000.00	1,071,000.00	
Total equipment.....				12,236,000.00
Real estate.....				989,000.00
Summation.....				32,281,000.00
Contingencies, 15 per cent of \$32,281,000.....				4,842,000.00
Engineering and superintendence, 10 per cent of \$32,281,000.....				3,228,000.00
Summation.....				40,351,000.00
Construction interest, 8 per cent of \$40,351,000.....				3,228,000.00
Construction cost.....				43,579,000.00
Cost per horsepower for 591,000 horsepower.....				73.70

The 6,000,000 cubic yards of rock and earth excavation from this project, exclusive of that from the power-house site and penstock tunnels, is to be placed along the shore of Niagara River between Grass Island and Cayuga Island, as shown on plate No. 33. This forms 407 acres of desirable land, and furnishes docking facilities for a score of ships of the size which can reach the harbor through existing channels. The cost of hauling the spoil to this place and dumping it has been included in the estimates above. The cost of dredging the slips, building dock walls, and purchasing adjacent land has not been included, because the value of the new land is estimated to more than offset the cost of these items.

The general plan of the power-canal proposition is shown on plate No. 33, and in greater detail on plate No. 39, where a profile of the selected route is given, as well as a large scale map. Plates Nos. 40 and 41 present outline designs of intake, fore bay, and power-house layouts.

It is entirely possible that further study might lead to a slightly more economical location for a power canal and also to a more economical cross section. The studies leading to the location and section adopted were based on unit prices somewhat different from those finally adopted. The change in section might involve not only variation in width and depth throughout the canal but also the use of concrete linings on sides or bottom and of riprap on earth slopes.

The above-given estimates show the two tunnel projects to be practically equal in cost and efficiency. Operation and maintenance costs should also be about the same. For supplying power to the factories now in existence the tailrace-tunnel plant has an advantage in location. For supplying new factories the two stand on an equality. Neither scheme can compete financially with the canal proposition, which is both cheaper and more efficient. The estimated construction cost per horsepower of the power canal development is only about 85 per cent of that of the tunnel projects. Its slightly greater operation and maintenance costs leave it still decidedly cheaper than the others in point of cost of electric energy produced.

There are certain serious defects inherent in the tailrace tunnel proposition which make it a project of very doubtful advisability both from a construction and from an operating standpoint. The construction difficulty lies in the fact that almost the whole of the tunnel would necessarily be below Lake Ontario level, where difficulty with ground water would be almost certain to occur. While it might be found that water would not accumulate in sufficient quantity to give appreciably more trouble than in the higher level pressure tunnel, there is a large chance that the trouble would be considerable. No allowance has been made in the estimate for this serious possibility.

From an operating point of view there are two important drawbacks. In the first place it may be advisable to maintain a large pumping plant at one end or the other of the tunnel, preferably the lower end, and to provide some sort of emergency gates at the lower end in order to be able to unwater the tunnel should it ever become necessary. Without such equipment great loss of time would ensue in unwatering. With the equipment all ready, it would take some time to pump out such a bore. The equipment might stand idle for 10 years at a time. The present tunnel of the Niagara Falls

Power Co. unwaters itself, because it is higher than the water into which it discharges, except right at the outfall. The tunnel under consideration in the tailrace-tunnel proposition would have to be as low as the tailwater level or great loss of power would result. In the second place there is the matter of surges in a tailrace tunnel so constructed. These might be very serious indeed, and no way of calculating or forecasting them has yet been developed. Serious surges have never occurred in the present tailrace tunnels at Niagara Falls, but conditions in them are not at all comparable with conditions in a low-level tunnel 48 feet in diameter and 5 miles long, serving units of three to five times the power. With proper draft tube efficiency the center of the turbine will have to be approximately 20 feet above the tail-water elevation, and even slight variations in this level will reduce efficiency and impair speed regulation, while large sudden changes would render speed regulation impossible and might produce shock and impact, causing serious stresses in the machinery. The regulators adopted for controlling surges in open canals and pressure tunnels do not appear to be adapted to the control of such a tunnel. Regulating reservoirs in the rock near the upstream end of the tunnel would involve prohibitive expense. The estimates do not include any pumping plant or tunnel gates or any regulators other than the synchronous relief valves on the penstocks. These latter would aid considerably in preventing surges, but their sufficiency is problematical.

If construction of the tailrace-tunnel proposition was undertaken, it might be found that ground water gave no special trouble. It might never become necessary to unwater the tunnel after its completion. In operating the plant there might never be any serious difficulty from surges, particularly in view of the use of synchronous relief valves. It is believed, however, that the chances of serious trouble along the lines indicated are sufficiently great to make the project of very doubtful advisability.

There is one important objection to the pressure-tunnel proposition, although it is not serious. It is this: If one of the penstock valves requires cleaning or repairs it will be necessary to shut down the entire plant and drain the tunnel. The plant would then remain down while repairs were being made unless the job was a long one, in which case the penstock tunnel leading to the valve would be bulkheaded and the plant started up, a second shutdown being required to remove the bulkhead. This difficulty could be obviated by adopting the construction advocated by the old Niagara Falls Power Co. and Hugh L. Cooper & Co., of leading the main tunnel up to a fore bay at the top of the bank, from which water would be fed to the turbines in long penstocks, as in the power-canal proposition. Such a construction would be much more expensive and less efficient, and does not appear justifiable. Other and cheaper means which might prove satisfactory have been suggested for at least greatly lessening the force of this objection.

The power-canal proposition presents some objections, none of which seem serious. From a construction point of view there is no particular difficulty involved, and from an operating viewpoint the only possibility of trouble is in the formation of ice in the canal. Under full operating conditions the current in the canal will be too swift to permit ice formation to any extent. When the plant first

commences to operate on one or two units, the current in the canal will be very slow and ice may form. There is, of course, the possibility that the plant might be shut down for several days during freezing weather, but this is remote, and it appears even less likely that both ice runs would be out of commission at such a time. The most important objection seems to be the presence of a large canal extending for miles through or near the city, with the necessity for bridge maintenance and all the attendant inconveniences. By disposing of the spoil along the shore of Niagara River, as suggested, there would not be the added objection of enormous piles of rock and earth along the sides of the canal. The canal would, nevertheless, partially prevent the use of valuable land for other purposes, form a dividing line disadvantageous to street and sewer systems, and cause the city or the company extra expense for building and maintaining bridges as the city grew.

In the pressure-tunnel and power-canal propositions the use of generating units of more than 37,000 horsepower each is readily possible. The Hydroelectric Power Commission of Ontario is said to have decided upon units of 52,500 horsepower each for its new development. The use of units of 60,000 horsepower each has been suggested. Such units would very likely be less expensive per horsepower than those included in the estimates. The manufacturers were not prepared to make estimates on such units. The 37,000-horsepower units proposed are to embody the most recent improvements, including either the hydraucone or an equally efficient form of draft tube.

Further consideration of and comparisons of these proposed developments are given in Section F-10, where the influence of such factors as rate of absorption of power, selling price of power, and cost of promoting and financing is pointed out.

4. PROPOSED PLANTS DIVIDING DIVERSION BUT USING FULL HEAD IN ONE STAGE.

The projects described previously for utilizing the full head are all based on the use of 20,000 cubic feet per second in a single plant. If this amount is to be used, there seems to be no advantage in having several plants whose total diversion amounts to 20,000 cubic feet per second. The cost of building two or more plants of the same total capacity would be a little greater than the cost of a single one, and the cost of operation would be somewhat greater. In case a revision of the treaty with Great Britain allowed a greater diversion than 20,000 cubic feet per second, it might be well to develop the total quantity in two or more parallel plants. A discussion of the proper limits to diversions around the Falls and around Whirlpool and Lower Rapids has been given in section E of this report. Should the desirability become apparent, a second plant could be constructed later for developing an additional 10,000 or 20,000 cubic feet per second.

The canal project could easily be doubled in size when first constructed, and the result would probably be a slight increase in efficiency and decrease in development cost per horsepower. A single-pressure or tailrace tunnel to carry 30,000 or 40,000 cubic feet per second seems impracticable, and the requirement of constructing two tunnels for such a diversion precludes any chance of appreciable

gain in efficiency or economy in such a development over the single 20,000 cubic feet per second development. In case a second like quantity were developed later, under like conditions, the entire works would simply be duplicated, including a new tunnel or canal, as the case might be. This procedure would be more economical ultimately than a method involving enlargement of the then existing canal or tunnel.

5. PROPOSED PLANTS DIVIDING DIVERSION AND DIVIDING HEAD.

From the Chippawa-Grass Island pool to the Maid of the Mist pool there is a gross head of about 220 feet. The existing plants all use this head, or part of it. It is possible to use the two present American plants, or one of the present ones and one new one, of the same head, combined with a development using the same diversion under the 90 feet of head in the rapids below the Falls. Any rational plan must involve the abandonment of the Niagara plant of the Niagara Falls Power Co. because of its incurable inefficiency. The same is true to a lesser extent of the Hydraulic Power Co.'s station 2. It then remains only to consider a new development, which, combined with the Hydraulic Power Co.'s station 3, will utilize 20,000 cubic feet per second under the 220-foot head, and another plant which will utilize 20,000 cubic feet per second under the 90-foot head. Outline plans and estimates for such an installation have been prepared. In Section E-6 a plan is considered which resembles this one, but in which the 220-foot development is a simple matter of one tunnel and one power house. The scheme here treated has a tunnel, a canal, and two power houses. To distinguish them, this one will be called the compound 2-stage proposition and the other one the simple 2-stage proposition.

Compound 2-stage proposition.—The hydraulic canal and station 3 of the Hydraulic Power Co. have already been described in Section F-2 of this report. With station 2 shut down, the maximum capacity of this plant at mean stage is about 6,650 cubic feet per second and 130,000 horsepower. The present flow through the canal is about 8,000 cubic feet per second. Investigation showed that it would be impossible to enlarge the canal to a capacity of 20,000 cubic feet per second without greatly reducing the present power output for many months while construction was in progress. The demand that the present supply of power be furnished without interruption is so important that such a course is practically impossible. As a new canal through the heart of the city is out of the question as regards both expense and desirability, the plan adopted involves a tunnel from Port Day.

The general outline designs are shown on plates Nos. 33, 42, 43, 44, and 45.

An approach channel is to be dredged in the river. This channel is curved in plan and extends from deep water 1,300 feet south of Grass Island to the canal entrance at Port Day. It is 3,000 feet long, 300 feet wide, and 20½ feet deep at mean stage. Near the outer end of this channel a new ice-diverting structure is built, consisting of strongly trussed booms floating between concrete piers. The Port Day entrance south of Buffalo Avenue is dredged to a depth of 20 feet on the east side and 36 feet on the west. Beyond Buffalo Avenue

about 88,000 yards of rock are dredged from the canal, effecting an average deepening of about 5 feet and enabling it to carry 10,000 cubic feet per second with a fall to the basin of only about 2.2 feet.

Along the west side of the Port Day entrance a tunnel intake is built. Fifteen panels of racks are supported between concrete piers 44 feet high, 45 feet long, and 5 feet thick, placed 25 feet center to center. The water enters the space between the piers through submerged arches 21 feet high at the springings and 26 feet at the crowns. Behind the racks are gates for use if it is desired to drain the tunnel. The entering water has a velocity of about 1.35 feet per second through the arches, 0.94 between the piers, and 1.3 through the racks.

The tunnel forebay runs behind the rack house. It is 20 feet wide by 36 feet deep at the south end, and 55 feet wide by 56 feet deep at the north. The velocity in it varies from 1 to $3\frac{1}{2}$ feet per second. From the north end of this forebay a short bellmouth section leads the water into the tunnel, where it attains a mean velocity of 9.68 feet per second.

The tunnel is of horseshoe-shaped cross section 35 feet in diameter. The top half is a 35-foot semicircle; below that the sides and invert each have a radius of 70 feet. The lining is of concrete 22 inches thick. At the start the tunnel slants downward at a slope of 2 horizontal to 1 vertical for about 150 feet, then makes a vertical curve of 125-foot radius and adopts a slope of 6 feet per 1,000. This brings it well below the city sewer tunnels and above the tunnel of the Niagara Falls Power Co. In plan the tunnel starts with a curve to the left with a radius of 1,275 feet. It then has a tangent bearing north 54° west, followed by a curve to the right with a radius of 430 feet. The whole length is 4,240 feet.

For hydraulic computations, Kutter's "N" was taken at 0.013. This gave a slope of 0.000439, and loss of head in the tunnel of 1.86 feet.

Near the lower end of the main tunnel a circular tunnel 30 feet in diameter rises to a "differential" surge tank in the open space between the flumes which supply water to station 2. The tank is of concrete, 95 feet in diameter, and rises 45 feet above the ground.

Beyond the end of the 35-foot tunnel is a tapering section 325 feet long. From this seven penstock tunnels branch off at an angle of 60° . They are circular, 15 feet in diameter, and average about 325 feet long. They enter a power house similar in design and equipment to that of the pressure-tunnel project, but containing only 10 units, each rated at 32,000 horsepower maximum. Best efficiency of these units is specified at about 30,000 horsepower. Seven of the units are supplied by the tunnel as described above. The other three are supplied from the canal.

The intake for the three units supplied from the canal is on the west side of the basin, between the central mill and the Schoelkopf & Mathews mill of the Niagara Milling Co. The south branch of the basin is filled in and the north branch widened to 100 feet abreast the intake. The face of the intake is flush with the west wall of the canal. It admits water through eight submerged arches 9 feet high to the springings and 14 feet to the crowns. The span of each arch is 16 feet, the crown being 9 feet below mean stage. The piers between arches are 4 feet thick. After passing the submerged arches the water flows between the same piers, which serve to hold up the

roadway. Behind the piers the water enters a small forebay, passes through a continuous line of racks, between a set of deep reinforced-concrete girders supporting the racks, and enters the three 15-foot penstock tunnels, each 350 feet long. The velocity is 2.63 feet per second through the arches, from $1\frac{1}{2}$ to 1 between the piers, and about 1.4 through the racks, 0.93 between the girders, and 8.2 in the penstock tunnels. There are no gates, but stop logs behind the arches serve to shut off the whole flow.

The power house on the talus slope is of the same general type as already described in the pressure-tunnel proposition, being equipped with penstock valves and vertical generating units. A lower part of the building over the tailraces contains bus bars, oil switches, and other accessories.

The mean stage of water surface at Port Day is 562 feet, and in the lower river abreast of the power house 343, giving a gross head of 219. For the three units fed from the basin the losses are estimated at 4.5 feet. Net head is 214.5 feet. For the other seven new units the losses are 5 feet and the net head 214. For station 3 the losses are 4 feet, exclusive of forebay, rack, and penstock losses, and the net head is 215 feet. Table No. 35 gives the power output.

TABLE NO. 35.—*Power output of compound two-stage proposition.*

Units.	Water required (cubic feet per second.)	Horse- power produced.	Maximum horse- power capacity.
3 new, from basin.....	4,350	91,000	96,000
7 new, from tunnel.....	10,150	212,000	224,000
5 direct-current, station 3.....	2,250	42,000	43,000
8 alternating current, station 3 (only 6 operated).....	3,250	64,000	87,000
Total.....	20,000	409,000	450,000

The horsepower produced is 20.4 per cubic foot per second.

It will be seen that the installation has a spare capacity of 41,000 horsepower, which permits shutting down any one unit without reducing the power output.

The estimated cost of new construction in this proposition is \$21,183,000, which is \$51.80 per horsepower, exclusive of the original cost of these parts of the existing plant incorporated in the design. Details are given in the estimate summary, Table No. 36. The estimated time of development is one year for the first power and three and one-fourth years for completion.

TABLE NO. 36.—*Compound two-stage proposition—Summary of estimate of construction cost.*

Item.	Quantity.	Unit price.	Amount.	Total.
UPPER STAGE.				
Dredging in river, hardpan.....cubic yards..	293,000	\$1.25	\$366,000.00	\$366,000.00
Ice protection, piers and booms.....lump..			200,000.00	
Total river work.....				
Cofferdam, D-22 feet.....linear feet..	400	194.00	78,000.00	
Earth excavation.....cubic yards..	16,100	1.75	28,000.00	
Rock excavation.....do.....	47,600	3.50	167,000.00	

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TABLE No. 36.—Compound two-stage proposition—Summary of estimate of construction cost—Continued.

Item.	Quantity.	Unit price.	Amount.	Total.
UPPER STAGE—continued.				
Plain concrete.....cubic yards.....	11,390	\$12.00	\$137,000.00	
Reinforced concrete.....do.....	980	25.00	24,000.00	
Steel reinforcement, extra.....pounds.....	102,000	.07	7,000.00	
Racks, steel.....do.....	1,005,000	.10	100,000.00	
Stop logs, steel.....do.....	64,500	.10	6,000.00	
Gates.....do.....	15	15,000.00	225,000.00	
Building.....square feet.....	18,450	12.00	221,000.00	
Total Port Day intake				\$693,000.00
Horseshoe tunnel, 35 feet diameter.....linear feet.....	4,240	450.00	1,909,000.00	
Tapering tunnel, 25 feet mean diameter.....do.....	325	325.00	106,000.00	
Circular tunnel:				
30 feet diameter riser.....do.....	210	549.00	115,000.00	
15 feet diameter.....do.....	3,328	157.00	522,000.00	
Shafts, 25 feet square.....cubic yards.....	12,800	12.00	154,000.00	
Total tunnels				2,806,000.00
Rock excavation.....do.....	3,540	3.75	13,000.00	
Earth excavation.....do.....	1,500	1.50	2,000.00	
Reinforced concrete:				
2½ per cent steel.....do.....	900	40.00	36,000.00	
1½ per cent steel.....do.....	220	30.00	7,000.00	
Plain concrete.....do.....	580	15.00	9,000.00	
Roof and incidentals.....do.....			10,000.00	
Total differential surge tank				77,000.00
Dredging hydraulic canal entrance, rock, cubic yards.....	40,700	25.00	1,018,000.00	
Dredging in hydraulic canal, rock.....do.....	78,700	25.00	1,968,000.00	
Dredging in basin, rock.....do.....	4,600	25.00	115,000.00	
Widening basin, rock, nearly all dredging.....do.....	8,400	20.00	168,000.00	
Concrete retaining walls.....do.....	3,650	15.00	55,000.00	
Total canal work				3,324,000.00
Rock excavation.....cubic yards.....	21,800	3.50	76,000.00	
Plain concrete.....do.....	3,120	15.00	47,000.00	
Reinforced concrete.....do.....	1,980	25.00	49,000.00	
Racks.....pounds.....	584,000	.10	58,000.00	
Stop logs.....do.....	172,900	.10	17,000.00	
Building.....square feet.....	8,200	12.00	98,000.00	
Total basin intake				345,000.00
Cofferdam, D-15.....linear feet.....	550	90.00	50,000.00	
Rock excavation.....cubic yards.....	52,900	3.50	185,000.00	
Plain concrete.....do.....	22,600	12.00	271,000.00	
Reinforced concrete.....do.....	4,200	25.00	105,000.00	
Building:				
High portion.....square feet.....	35,100	15.00	526,000.00	
Low portion.....do.....	14,590	12.00	175,000.00	
Total power house				1,312,000.00
Penstocks, steel.....pounds.....	781,000	.10	78,000.00	
Penstock valves.....do.....	10	53,000.00	530,000.00	
Turbines and generators.....horsepower.....	320,000	15.20	4,864,000.00	
Erection and accessories.....do.....	320,000	3.40	1,088,000.00	
Total equipment				6,560,000.00
Real estate.....do.....				156,000.00
Summation				16,139,000.00
Contingencies, 15 per cent of \$16,139,000.....				2,421,000.00
Engineering and superintendence, 10 per cent of \$16,139,000.....				1,614,000.00
Summation				20,174,000.00
Construction interest, 5 per cent of \$20,174,000.....				1,009,000.00
Construction cost				21,183,000.00
Cost per horsepower for 409,000 horsepower.....				51.80
LOWER STAGE.				
Reversing tailraces, upper station.....			180,000.00	
Revenue from power lost when reversing tailraces.....			500,000.00	
Total reversing under plant discharge				680,000.00
Circular tailrace tunnel:				
16 feet diameter.....linear feet.....	1,250	167.00	209,000.00	
10 feet diameter.....do.....	2,580	105.00	271,000.00	
4 feet diameter.....do.....	410	45.00	18,000.00	

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TABLE NO. 36.—*Compound two-stage proposition—Summary of estimate of construction cost—Continued.*

Item.	Quantity.	Unit price.	Amount.	Total.
LOWER STAGE—continued.				
Taper horseshoe tunnel, mean diameter 39 feet, linear feet.....	1,195	\$580.00	\$693,000.00	
Horseshoe tunnel, 48 feet diameter..... linear feet..	19,900	735.00	14,626,000.00	
Taper horseshoe tunnel, mean diameter 32 feet, linear feet.....	665	440.00	293,000.00	
Circular penstock tunnels, 15 feet diameter, linear feet.....	1,850	156.00	289,000.00	
Shafts, 25 feet square..... cubic yards.....	31,970	12.00	384,000.00	
Total tunnels.....				\$16,783,000.00
Circular tunnel, 16 feet diameter..... linear feet..	140	167.00	23,000.00	
Shaft..... cubic yards.....	4,130	12.00	50,000.00	
Plain concrete..... do.....	640	15.00	10,000.00	
Steel, penstock, etc..... pounds.....	138,500	.10	14,000.00	
Penstock valve, 16 feet diameter.....	1	53,000.00	53,000.00	
Miscellaneous.....			5,000.00	
Total by-pass.....				155,000.00
Rock excavation..... cubic yards.....	78,000	3.50	273,000.00	
Plain concrete..... do.....	14,840	12.00	178,000.00	
Reinforced concrete..... do.....	630	25.00	16,000.00	
Cofferdam, D-10 feet..... linear feet.....	300	40.00	12,000.00	
Horseshoe tunnel, 30 feet diameter..... do.....	240	368.00	88,000.00	
Building..... square feet.....	5,700	12.00	68,000.00	
Gates, steel..... pounds.....	1,030,000	.10	103,000.00	
Special machinery for gates.....			50,000.00	
Rebuilding Gorge route tracks.....			2,000.00	
Total surge spillway.....				790,000.00
Rock excavation..... cubic yards.....	186,300	3.50	652,000.00	
Cofferdam, D-15 feet..... linear feet.....	800	90.00	72,000.00	
Plain concrete..... cubic yards.....	39,150	12.00	470,000.00	
Reinforced concrete..... do.....	1,080	25.00	27,000.00	
Building..... square feet.....	64,600	15.00	969,000.00	
Rebuilding Gorge route tracks.....			5,000.00	
Total powerhouse.....				2,158,000.00
Penstocks, steel..... pounds.....	982,500	.10	98,000.00	
Synchronous relief valves.....	10	10,000.00	100,000.00	
Do.....	13	5,000.00	65,000.00	
Turbines and generators..... horsepower.....	182,000	16.30	2,967,000.00	
Erection and accessories..... do.....	182,000	3.50	637,000.00	
Penstock valves.....	14	43,000.00	602,000.00	
Interlocking signalling and operating equipment.....			53,000.00	
Total equipment.....				4,519,000.00
Real estate.....				108,000.00
Summation.....				25,173,000.00
Contingencies, 15 per cent of \$25,173,000.....				3,776,000.00
Engineering and superintendence, 10 per cent of \$25,173,000.....				2,517,000.00
Summation.....				31,466,000.00
Construction interest, 9 per cent of \$31,466,000.....				2,822,000.00
Construction cost.....				34,298,000.00
Cost per horsepower for 161,000 horsepower.....				209.10
BOTH STAGES COMBINED.				
Construction cost of upper stage.....				21,183,000.00
Construction cost of lower stage.....				34,298,000.00
Construction cost of entire proposition.....				55,481,000.00
Cost per horsepower for 373,000 horsepower.....				96.40

For the lower stage plant two methods present themselves. The water from the upper stage tailraces may be collected and used again, or it may be turned into the Maid of the Mist pool and the water required for the lower plant taken independently from that pool at some point near the railroad bridges. The second method is obviously cheaper as regards original construction, for it shortens the length of tunnel required by about a mile. It also provides for a

much more flexible and independent operation of the two plants. There are, however, three serious objections to this plan. In the winter the Maid of the Mist pool often carries enormous quantities of ice. The same amount of ice which passes the intakes on the upper river, distributed over a waterway from 5,000 to 7,500 feet wide, will pass this intake with a width of waterway of only 500 to 1,000 feet, depending on the intake location. It can be expected from this concentration that ice trouble will be many times as great as in the cases of the present plants, whose troubles have often been severe. Ice bridges frequently form in the upper part of the pool, and then move down as a solid mass until they are broken up at the railroad bridges. The second disadvantage of an intake in this pool arises from the violent fluctuation in surface level to which it is subject. These changes in water surface elevation are at present more than four times as great as in the Chippawa-Grass Island pool. Systematic records of the fluctuations are not available, but the records during the winter of 1917-18 of a gauge maintained by the Hydraulic Power Co. showed a range from 336.5 to 356 feet. The range during a number of years must be much greater. If 40,000 cubic feet per second is diverted around the Whirlpool Rapids, the level of the Maid of the Mist pool will be lowered, the amount of lowering being greater at low than at high stages. At the low stage of January 28, 1918, the level would have been reduced from 336.5 to 330.4 feet. For a diversion of 80,000 cubic feet per second the level would have been about 323.5 feet. The third objection is that floating weeds and trash, a very bothersome amount of which sometimes comes down the river, must again be separated from the water in the second method, while in the first method there is no chance for a second accumulation.

It appears, therefore, that an intake in the Maid of the Mist pool must be so designed as to be able to handle floating weeds and trash, ice jams, vast quantities of floating ice, and fluctuations of stage as great as 30 feet. The turbines served by such an intake will be subject to fluctuations of head amounting to more than 30 per cent of the mean net head, which means considerable reduction in the amount of continuous power they can turn out, lessened efficiency, and increased difficulties of operation.

In view of these facts, it was decided that any lower stage plant should be of the type not taking water from the Maid of the Mist Pool, and the outline plans prepared therefore provide for gathering the discharge from the upper head plant before it is permitted to enter the Maid of the Mist pool.

The draft tubes of station 3 and of the new upper stage plants are reversed and discharge away from the river into tailrace tunnels which are 10 feet in diameter for the station 3 units and 16 feet for the new ones. These tunnels join a gradually enlarging main tailrace tunnel which reaches 48 feet in diameter at the point where it receives the tunnel from the last unit. A 16-foot by-pass tunnel with a valve connects the headrace tunnel with the tailrace tunnel to supply water to the lower plant when part of the upper plant is shut down. All the turbines in the upper plants are provided with synchronous relief valves.

The main tunnel is of horseshoe-shaped cross-section, 48 feet in diameter, side and bottom radii 96 feet. Its hydraulic properties are

exactly the same as those of the tunnel described in Section F-3 of this report under the heading "Tailrace tunnel." It is 19,900 feet long.

To allow the upper plant to operate at times with a water consumption greater than that of the lower plant a spillway is provided near the lower end of the tunnel. A basin 267 feet long by 50 feet wide is dug in the talus slope, and connected to the tunnel by two short tunnels, each 30 feet in diameter. Along the front of the basin is a spillway weir with 10 segmental gates, which form a movable crest. These gates are each 24 feet long and operate between concrete piers 3 feet thick. The movable crest has a range of 14 feet. The machinery for operating the crest is in a building supported on the piers. The spillway slopes down under the Gorge Route tracks and discharges into the river. With the gates in their lowest position, this spillway will discharge the full tunnel capacity of 20,000 cubic feet per second, with practically no change in head on the upper plant.

The power house is just downstream from the spillway. Fourteen circular penstock tunnels, 15 feet in diameter and about 132 feet long, branch off from a tapering section of the main tunnel. The power house in the talus slope is of the same type as in the pressure tunnel proposition and has the same arrangement of penstock valve, turbine, generator, and draft tube. It contains 14 units each rated at 13,000 maximum horsepower. Thirteen machines can carry the full load.

It is intended to operate the plants with a mean tail-water elevation of 343 at the upper station. At mean stage the tail-water elevation of the lower plant is 250, which gives a gross head of 93 feet. The total hydraulic losses in the lower development are estimated at 9 feet, of which the principal part, namely 6.75 feet, occurs in the main tunnel. The net head remaining is 84 feet. With 86 per cent efficiency of machinery, a diversion of 20,000 cubic feet per second gives an output of 164,000 horsepower. This is 8.2 horsepower per cubic foot per second.

The two plants combined have a gross head of 312 feet, an output of 573,000 horsepower, and an over-all efficiency of 81 per cent. They develop 28.6 horse power per cubic foot of water diverted per second.

The estimated cost of the lower stage plant is \$34,298,000, which is \$209.10 per horsepower. For the two plants combined the cost is \$55,481,000, or \$96.80 per horsepower then available. A summary of the estimates is given in Table No. 36. The estimated time of development of the lower river plant is two and one-fourth years for the first power and four and one-fourth years for completion. Certain details of the design upon which the estimate was based are shown on plates Nos. 42 to 45, inclusive.

The critical element of this scheme is the operation. The upper and lower plants must be operated as a unit and great care must be taken by the use of the by-pass, relief valves, and spillway to maintain a uniform flow. It must be positively assured that the opening of a circuit breaker in the upper plant will either admit extra water to the tunnel to compensate for the shutting down of the unit, or else will close the gates in the lower station on a unit which is using an approximately equal quantity of water; otherwise the supply of water to the lower plant is likely to be diminished suddenly under

full load, causing a reduction in speed of the generating units, with consequent undesirable and even dangerous operating conditions. Under such circumstances there is danger of sucking air into the turbines in sufficient quantity to cause destructive shocks and stresses, and there is also danger of damage to the electrical machinery.

Because of this uncertain element of danger in operation, the Hydraulic Power Co. has modified its original plans as presented in Exhibit B of the interim report of March 2, 1918, and is arranging to have the units discharge into a tail-bay between the power house and the Maid of the Mist pool. The tail-bay has free communication with the pool, and ordinarily will be at the same level. It will discharge into the pool until such time as the down-river plant is constructed and placed in operation, and thereafter whenever the down-river plant is not drawing all the water discharged from the upper plant. The tail-bay becomes a head-bay for the down-river plant, feeding the upper end of the tunnel through two short tunnels beneath the power house. Gates are provided for closing the two tunnel entrances, and also for shutting the tail-bay off from the river. The advantages of this design are, first, provision for discharging surplus water into the Maid of the Mist pool; second, provision for supplying the down-river plant automatically with water from the Maid of the Mist pool in case of loss of load on upper plant; third, simplicity of control at upper end of main tunnel and between tail-bay and Maid of the Mist pool. The disadvantages are about the same as those already enumerated for the intake near the railroad bridges. Also the loss of head will probably be greater than with the arrangement proposed herein. The change will prove advantageous if the lower stage is never developed.

The above-described outline plans and estimate were prepared before the change in plans by the Hydraulic Power Co. had been determined upon. In fact, they follow the original plans of that company fairly closely, although deviating considerably from them in certain particulars. All three schemes will cost about the same, however, and it seems unnecessary for the purposes of this report to change the plans and estimates here given in an attempt to be in accord with later developments, the designs for which are being altered frequently.

The matter of surges in the long tunnel which forms a tailrace for one plant and a headrace for another, deserves the most careful consideration. It appears much more difficult to regulate surges in this tunnel than in the simple headrace pressure tunnel, but regulation seems easily within the range of practicable possibility, and the problem is far less difficult than the one presented in the tailrace-tunnel proposition. With the by-pass, relief valves, spillway, and interlocking and automatic electrical control suggested, it is believed good regulation and freedom from serious accident could be secured. As an extra precaution against possible flooding of the upper power houses a spillway might be located near the upper end of the long tunnel, so arranged as to discharge into the Maid of the Mist pool any part of the full 20,000 cubic feet per second when the water arose above an elevation of about 355. The desirability of the use of a differential surge tank at the downstream end of this tunnel, with consequent modification of or elimination of the spillway herein provided, deserves careful study.

6. PROPOSED PLANTS USING FULL DIVERSION BUT DIVIDING HEAD.

Simple two-stage proposition.—An outline design and estimate was made for an installation to use a diversion of 20,000 cubic feet per second in two stages, there being only one power house for each stage. The studies already referred to in Section F-5 determined that it should be a self-contained system without connection to the Maid of the Mist pool. Plate No. 33 shows the general layout of the project. In this proposed development an approach channel is to be dredged in the river similar to the one in the tailrace tunnel proposition Section F-3, but extending downstream to Grass Island. On Grass Island is built an intake exactly like the one described in the pressure-tunnel proposition. A 48-foot tunnel 8,500 feet long, similar to those already described, leads to a point in the Gorge near the car barns of the Gorge Route Railway. The tunnel passes just south of the wheel pit of station No. 2 of the Niagara Falls Power Co., and 30 to 40 feet above the tailrace tunnels leading from the turbines of this company and the International Paper Co. At the lower end of the tunnel, between the New York Central and Gorge Route tracks, is a differential surge tank 105 feet in diameter and 90 feet high. Fifteen penstock tunnels, each 15 feet in diameter, branch off from a tapering section of tunnel in the usual manner. Entering the power house the water passes through penstock valves and turbines and discharges into a tailrace tunnel running longitudinally under the power house as in the tailrace-tunnel proposition. Fifty feet downstream from the power house a 500-foot length of the tailrace tunnel is opened up to the surface of the talus slope to form a temporary spillway so that the upper plant can be used alone during the construction of the downstream plant.

The 15 units installed in this plant are rated at 32,000 maximum horsepower. They are to be vertical-shaft machines of the general type and characteristics already described for the upper station of the compound two-stage development.

When this plant is running independently the gross head is 215.25 feet. The total losses are estimated at 7 feet, of which 3.25 feet occur in the main tunnel. The net head is 208.25 feet, and power output 460,000 horsepower, or 20.3 horsepower per cubic foot per second.

The cost is estimated at \$31,528,000, which is \$77.70 per horsepower. A summary of the estimate is to be found in Table No. 37.

The lower stage development is exactly like that described in Section F-5 for the compound two-stage proposition, except that the length of the 48-foot tunnel is only 17,200 feet from the downstream end of the temporary spillway, or 17,750 feet from the power house. Considering the upper and lower developments as a unit the gross head is 312.25 feet and the total losses 14.75 feet, of which 3.25 feet occurs in the upper tunnel and 6 in the lower. The net head is 297.5 feet; power output, 580,000 horsepower, or 29 horsepower per cubic foot per second; and overall efficiency 81.9 per cent. The cost of the two plants is estimated at \$61,227,000, which is \$105.60 per horsepower. Table No. 37 contains the estimate summary. Certain details of the design upon which the estimate was based are shown on plates Nos. 46 to 48, inclusive.

The estimated time of development is two years for the first power and four and one-half years for completion of the upper plant; and, measuring from the commencing of the lower plant, two years for the first power from it and four and one-fourth years for its completion.

The difficulties in operating this plant would be much the same as in the case of the compound two-stage proposition, as already described in Section F-5.

TABLE No. 37.—*Simple two-stage proposition—Summary of estimate of construction cost.*

UPPER STAGE.

Item.	Quantity.	Unit price.	Amount.	Total.
Predging in river, hardpan.....cubic yards..	835,700	\$1.25	\$1,045,000.00	
Total river work.....				\$1,045,000.00
Cofferdam, D-5 feet.....linear feet..	2,200	10.00	22,000.00	
Rock excavation.....cubic yards..	94,500	3.50	331,000.00	
Plain concrete.....do..	26,220	12.00	315,000.00	
Reinforced concrete.....do..	2,320	25.00	58,000.00	
Rails.....pounds..	880,000	.10	88,000.00	
Stop logs (steel).....do..	102,000	.10	10,000.00	
Gates.....	30	19,000.00	570,000.00	
Building.....square feet..	48,000	12.00	576,000.00	
Total intake.....				1,970,000.00
Main tunnel, 48 feet diameter.....linear feet..	8,500	735.00	6,248,000.00	
Tapering tunnel, 32 feet mean diameter.....do..	700	440.00	308,000.00	
Shafts, 25 feet square.....cubic yards..	16,200	12.00	194,000.00	
Penstock tunnels, 15 feet diameter.....linear feet..	3,525	157.00	553,000.00	
Downtake shaft, 50 feet diameter.....do..	96	1,185.00	114,000.00	
Tailrace tunnel, 48 feet diameter.....do..	50	735.00	37,000.00	
Total tunnels.....				7,454,000.00
Rock excavation.....cubic yards..	12,700	3.00	38,000.00	
Reinforced concrete:				
2 per cent steel.....do..	1,100	35.00	38,000.00	
3½ per cent steel.....do..	2,780	47.50	132,000.00	
Plain concrete.....do..	930	15.00	14,000.00	
Tunnel connection, 43 feet diameter.....linear feet..	145	915.00	133,000.00	
Roof and miscellaneous.....			15,000.00	
Total surge tank.....				370,000.00
Rock excavation.....cubic yards..	140,500	3.50	492,000.00	
Plain concrete.....do..	48,080	12.00	577,000.00	
Building:				
Over generating units.....square feet..	40,600	15.00	609,000.00	
Over valves.....do..	27,300	12.00	328,000.00	
Total power house.....				2,006,000.00
Rock excavation.....cubic yards..	119,200	3.50	417,000.00	
Plain concrete.....do..	4,600	15.00	69,000.00	
Total temporary spillway.....				486,000.00
Penstocks and draft tubes (steel).....pounds..	2,070,000	.10	207,000.00	
Turbines and generators.....horsepower..	480,000	15.20	7,296,000.00	
Erection and accessories.....do..	480,000	3.40	1,632,000.00	
Penstock valves.....	15	53,000.00	795,000.00	
Synchronous relief valves.....	15	10,000.00	150,000.00	
Total equipment.....				10,080,000.00
Real estate.....				161,000.00
Summation.....				23,572,000.00
Contingencies, 15 per cent of \$23,572,000.....				3,536,000.00
Engineering and superintendence, 10 per cent of \$23,572,000.....				2,357,000.00
Summation.....				29,465,000.00
Construction interest, 7 per cent of \$29,465,000.....				2,063,000.00
Construction cost.....				31,528,000.00
Cost per horsepower for 406,000 horsepower is.....				77.70

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TABLE No. 37.—Simple two-stage proposition—Summary of estimate of construction cost—Continued.

LOWER STAGE.				
Item.	Quantity.	Unit price.	Amount.	Total.
Plain concrete.....cubic yards	4,600	\$15.00	\$69,000.00	
Filling temporary spillway.....			100,000.00	
Revenue from power lost when closing spillway.....			500,000.00	
Total cost of closing spillway.....				\$669,000.00
Main tunnel, 48 feet diameter.....linear feet	17,200	735.00	12,642,000.00	
Taper tunnel, mean diameter 32 feet.....do	665	440.00	293,000.00	
Circular penstock tunnels, 15 feet diameter.....do	1,850	156.00	289,000.00	
Shafts, 25 feet square.....cubic yards	31,979	12.00	384,000.00	
Total tunnels.....				13,608,000.00
Circular tunnel, 16 feet diameter.....linear feet	300	167.00	50,000.00	
Shaft.....cubic yards	4,130	12.00	50,000.00	
Plain concrete.....do	640	15.00	10,000.00	
Steel, penstock, etc.....pounds	138,500	.10	14,000.00	
Penstock valve, 16 feet diameter.....	1	53,000.00	53,000.00	
Miscellaneous.....			5,000.00	
Total by-pass.....				182,000.00
Rock excavation.....cubic yards	78,000	3.50	273,000.00	
Plain concrete.....do	14,940	12.00	178,000.00	
Reinforced concrete.....do	630	25.00	16,000.00	
Cofferdam, D=10 feet.....linear feet	300	40.00	12,000.00	
Horseshoe tunnel, 30 feet diameter.....do	240	366.00	88,000.00	
Building.....square feet	5,700	12.00	68,000.00	
Gates, steel.....pounds	1,030,000	.10	103,000.00	
Special machinery for gates.....			50,000.00	
Rebuilding Gorge Route tracks.....			2,000.00	
Total surge spillway.....				790,000.00
Rock excavation.....cubic yards	186,300	3.50	652,000.00	
Cofferdam, D=15 feet.....linear feet	800	90.00	72,000.00	
Plain concrete.....cubic yards	36,150	12.00	434,000.00	
Reinforced concrete.....do	1,060	25.00	26,000.00	
Building.....square feet	64,600	15.00	969,000.00	
Rebuilding Gorge Route tracks.....			5,000.00	
Total power house.....				2,158,000.00
Penstocks, steel.....pounds	982,500	.10	98,000.00	
Synchronous relief valves.....	15	10,000.00	150,000.00	
Turbines and generators.....horsepower	182,000	16.30	2,967,000.00	
Erection and accessories.....do	182,000	3.50	637,000.00	
Penstock valves.....	14	43,000.00	602,000.00	
Interlocking signaling and operating equipment.....			50,000.00	
Total equipment.....				4,504,000.00
Real estate.....				82,000.00
Summation.....				21,999,000.00
Contingencies, 15 per cent of \$21,999,000.....				3,300,000.00
Engineering and superintendence, 10 per cent of \$21,999,000.....				2,200,000.00
Summation.....				27,499,000.00
Construction interest, 8 per cent of \$27,499,000.....				2,200,000.00
Construction cost.....				29,699,000.00
Cost per horsepower for 174,000 horsepower.....				170.70
BOTH STAGES COMBINED.				
Construction cost of upper stage.....			\$31,528,000.00	
Construction cost of lower stage.....			29,699,000.00	
Construction cost of entire proposition.....			61,227,000.00	
Cost per horsepower for 180,000 horsepower.....				105.60

7. POWER DEVELOPMENT COMBINED WITH SHIP CANAL.

The investigations of the Board of Engineers on Deep Waterways, made July, 1897–June, 1900, and reported in House of Representatives Document No. 149, Fifty-sixth Congress, second session, established the La Salle-Lewiston route as the most economical and satisfactory general location for a ship canal between Lake Erie and Lake Ontario, on the United States side of the international boundary.

After careful study of the report of this board, and reconnaissance of the terrain lying between the two lakes and from the Niagara River eastward to Lockport, it was decided that there is no reason apparent why this superiority does not still exist. The identical alignment adopted by the board was assumed as a basis for the estimates here given, although it was thought further study might lead to selection of a slightly different alignment, particularly in the vicinity of La Salle. A considerably more spacious and commodious entrance from Niagara River into the head of the canal than that herein provided might be desirable, in order to minimize difficulties and dangers to vessels navigating the entrance. The number, arrangement, and location of locks was likewise taken the same as in the plans presented by the board, although it was realized that the tendency of recent design is toward fewer locks and higher lifts, and that more extended and detailed study might demonstrate the desirability of fewer locks in this instance.

The canal cross-section in rock cut, as recommended by the board, was 240 feet wide and 21 feet deep. It was designed for use by boats 480 feet long, 52 feet beam, and 19 feet draft, this being the size of boat then considered most economical for lake service where limiting channels were 21 feet deep. The largest vessel then existing on the Great Lakes, the freight steamer *John W. Gates*, was 478 feet long, 52 feet beam, and 30 feet molded depth. The steam freight vessel, *W. Grant Morden*, now the largest boat in commission on the Lakes is 625 feet long, 59 feet beam, and 32 feet molded depth. A number of other lake freighters over 600 feet long have a beam of 64 feet. At present the draft of these boats is limited by the depths available in certain dredged channels, and varies from 19 feet to 21 feet, depending on lake stages, for navigation between Lake Erie and the upper lakes. At present the limiting depths are to be found in the Grosse Pointe Channel at the foot of Lake St. Clair. There the depth is 20 feet below the low water datum plane, which is at elevation 573.8. In deep water these large freighters could load several feet deeper. The size of the locks and channels of the St. Lawrence River Canals, and the present Welland Canal, limits the size of vessels plying between Lake Ontario ports and Lake Erie, or the Atlantic Ocean, to 255 feet length, 43 feet beam, and 14 feet draft.

For the needs of navigation only a canal width of 200 feet is proposed, this being the width of the new Welland Canal, now under construction, and also of the Black Rock Canal, except on curves, where it is wider. The depth should be equal to the depth provided in the new Welland Locks, namely, 30 feet. From the point of view of navigation, a ship canal connecting Lakes Erie and Ontario has been discussed in Section A of this report. The following paragraphs treat of a ship canal combined with a power development.

In carrying 20,000 cubic feet of water per second for power development through a canal 200 feet wide and 30 feet deep a mean current velocity of 3.33 feet per second, or 2.3 miles per hour, would prevail, and this would be increased at times when the upper locks were being filled. A perfectly satisfactory canal might be 300 feet wide and 40 feet deep, or 400 feet wide and 30 feet deep. Such a canal would pass a flow of 20,000 cubic feet per second, with a mean velocity of 1.67 feet per second, or 1.14 miles per hour. At the La

Salle entrance a canal section 400 feet wide and 30 feet deep is both more commodious for vessels entering and more economical of construction than a section 300 feet wide and 40 feet deep. At station 930 of the deep-waterways route it becomes more economical to construct the section 300 feet wide and 40 feet deep, because of the heavy overburden of solid rock. The 300-foot width is superior in this point of economy from this point to the locks. A slight economy might be effected by narrowing to 300 feet before reaching the railroad bridges in La Salle, but this is doubtful, and the extra width is desirable where bridges are clustered so closely together. The section finally adopted is 400 feet wide and 30 feet deep below elevation 561 (which is 1.5 feet below standard low water at Cayuga Island) from the river entrance to station 926. In the next 800 feet it narrows 100 feet and deepens 10 feet. From station 934 to station 1166 it is 300 feet wide and 40 feet deep. In the next 800 feet it changes to 400 feet width and 30 feet depth, and thence it maintains these dimensions to station 1210, near the locks. This last widened portion enables vessels to keep away from the power-canal intake and leaves more room just above the locks for mooring, passing, or lying in wait.

For the sake of comparison, estimates are also given for a canal 200 feet wide by 33 feet deep and for a canal 400 feet wide and 30 feet deep throughout its entire length.

The locks were made of approximately the same size as those of the new Welland Canal.

At present there is a good channel for the largest lake boats from Lake Erie through the Black Rock Ship Canal and Lock and down the American channel to the Wickwire Steel Co. docks, and projects have been adopted for continuing the improvements to North Tonawanda.

From the lumber docks at North Tonawanda to La Salle 9 or 10 feet is the maximum depth. In this ship-canal project it is proposed to dredge a channel throughout this reach 400 feet wide and 21 feet deep at standard low water, corresponding in dimensions with the Strawberry Island channels above.

The entrance to the ship canal is to be at La Salle, at the upper entrance to the Little River behind Cayuga Island. For the last 4,000 feet of dredged channel where vessels would be turning into the entrance, and where a cross current exists, the dredged channel is to be 600 feet wide. The entrance has concrete piers on each side and a heavy boom that can be swung across in winter, the whole being designed to divert ice. The velocity in the 400-foot canal is 1.67 feet per second, and in the entrance where the ice boom floats it is approximately 1 foot per second. As the river current past the entrance is roughly 2 feet per second, there should be no great difficulty in keeping ice out of the canal unless the river should freeze from shore to shore, a thing which did not occur in the extremely cold winter of 1917-18.

The sides of the canal are to be channeled in about 10-foot lifts in rock cut, the canal bottom having the full nominal width. At elevation 571, above high water, there is a 10-foot berm on each side. At the top of the rock surface is another 10-foot berm. When the rock surface does not rise to elevation 571, reinforced concrete retaining walls are built to that height. Earth slopes are 1 on 2.

There is one double flight of six locks with a total lift of 242 feet, and one double flight of two locks with a total lift of 74 feet. The locks are of the design of the Deep Waterways Board modified to give them a length of 800 feet between hollow quoins, clear width of 80 feet, and minimum depth of water on the sills of 30 feet. They have the usual double-leaf mitering gates and guard gates, and are all founded on rock.

Below the locks is an entrance between diverging piers 1,500 and 2,250 feet long, respectively. The piers have mooring facilities for several of the largest boats. The river below the locks has a depth varying from 35 to 72 feet. Just outside the river mouth, about two-thirds of a mile north by east from Fort Massasauga is a shoal with a least depth of about 13 feet. Here a channel is to be dredged 600 feet wide and 25 feet deep at low water. This is wider and deeper than the channels in the upper river because of the violent sea to which this entrance is exposed in northeasterly gales. From this point on in Lake Ontario there is ample water for all vessels if they keep east of Niagara River gas and bell buoy.

Water for power generation is taken from the ship canal about 3,000 feet above the upper locks. Here the ship canal is making a curve to the right on a radius of 8,800 feet. Along the outside of this curve is a concrete wall of 12 feet wide at the top, 30 feet wide at the bottom, and 2,130 feet long. It is pierced by 35 arches of 30-foot span each. The arches are 10 feet high at the springings and 20 feet at the crowns. The crowns are thus 10 feet below low water. The piers between arches are 30 feet wide. This structure has been made very massive to resist the impact of ships that might accidentally collide with it, and very long so that the "cross current" produced would not interfere appreciably with navigation. The velocity of the cross current is estimated to be about 0.3 foot per second. The velocity through the arches is 1.07 feet per second.

Just north of the arch wall is an ice run. This is a double weir having an effective length of 30 feet, and closed by two gates which can be lowered to elevation 545. Water and ice falling over the weir flow through a tunnel 12 feet in diameter to the lower river. With the water lowered to 8 feet below mean stage the capacity of this ice run is about 2,500 cubic feet per second, while at mean stage it is 3,000 to 4,000. A small house covers the gates and operating machinery.

Behind the arches the water enters a basin 2,070 feet long, varying in width from 10 to 317 feet. It is 30 feet deep at low water. From the wider end of the basin, which is downstream, runs a canal which rapidly contracts to a wetted section 58 feet wide by 58 feet deep. This canal is about 2,000 feet long, and approximately half of its length is on a curve of 1,010-foot radius. The sides are channeled and the bottom lined with concrete. At the lower end it expands to a section 172 feet wide with a depth of 58 feet. Here the water enters the fore bay 900 feet long, which is 58 feet deep at mean stage. From upstream to downstream end the fore bay tapers in width from 172 to 20 feet. Along the west edge of the fore bay are the rack house and an ice run.

The ice run is at the upstream end of the rack house. It is exactly like the other ice run outside of the arch wall in the ship canal. The rack house has about the usual arrangement of submerged arches and

racks supported by piers. There are bell-mouthed entrances to 17 penstock tunnels, each 15 feet in diameter. The flow to each penstock is controlled by a pair of gates, 20 feet wide and 30 feet high.

At mean stage the velocities of the water are 1.07 feet per second through the outer arches, 5.95 in the central section of the canal, 1.67 through the racks, and 6.67 in the penstock tunnels.

The power house on the talus slope is similar to that outlined in the headrace tunnel proposition, except that it has no penstock valves. Its 17 units are rated at 38,000 horsepower each, giving a total of 646,000 rated horsepower. Sixteen machines can carry the total load. The gross head on this plant at mean stage is 316.4 feet. The total hydraulic losses are estimated at 3.5 feet, giving a net head of 312.9 feet. At 20,000 cubic feet per second this gives 611,000 horsepower. This is 80.6 horsepower per cubic foot per second, and shows an overall efficiency of 85 per cent.

In estimating the cost of the power development it was considered that all parts of the canal necessary to navigation were public structures built for free public use, and that construction interest should not be charged against them. The estimated total cost was \$198,412,000, which is \$324.70 per horsepower. The cost of the part necessitated for power purposes alone is \$93,000,000 or \$97.50 per horsepower. A summary of the estimate is given in Table No. 38. The general layouts of certain main features of the design upon which the estimate was based are shown on plates Nos. 49 to 51.

TABLE No. 38.—*Ship canal proposition—Summary of estimate of construction cost.*

Item.	Quantity.	Unit price.	Amount.	Total.
Dredging in upper river, hardpan..... cubic yards..	2, 872, 000	\$1.25	\$3, 590, 000.00	
Total upper river work.....				\$3, 590, 000.00
Dredging earth and hardpan..... do.....	156, 900	1.25	196, 000.00	
Dredging rock..... do.....	143, 200	6.50	931, 000.00	
Back fill..... do.....	5, 900	.45	2, 655.00	
Plain concrete..... do.....	26, 700	12.00	320, 400.00	
Riprap..... do.....	23, 500	1.00	23, 500.00	
Log boom pontoons..... do.....	38	1, 800.00	68, 400.00	
Total La Salle entrance.....				1, 542, 000.00
Earth excavation..... cubic yards.....	10, 856, 000	.65	7, 056, 400.00	
Rock excavation..... do.....	18, 786, 000	1.95	36, 594, 000.00	
Do..... do.....	6, 492, 000	1.90	12, 335, 000.00	
Reinforced concrete, 0.37 per cent steel..... do.....	148, 200	18.70	2, 771, 000.00	
Back fill..... do.....	803, 000	.45	361, 350.00	
Oak fenders..... feet b. m.....	170, 000	150.00	25, 500.00	
Weirs.....			40, 000.00	
Total main canal.....				59, 183, 000.00
Earth excavation..... cubic yards.....	2, 440, 000	.65	1, 586, 000.00	
Rock excavation..... do.....	5, 860, 000	2.25	13, 185, 000.00	
Plain concrete..... do.....	2, 936, 000	12.00	35, 232, 000.00	
Back fill..... do.....	416, 000	.45	187, 200.00	
Reinforcing steel..... pounds.....	6, 800, 000	.07	476, 000.00	
Structural steel..... do.....	20, 830, 000	.10	2, 083, 000.00	
Steel castings..... do.....	6, 090, 000	.12	731, 000.00	
Steel forgings..... do.....	75, 000	.20	15, 000.00	
Bronze..... do.....	25, 000	.80	20, 000.00	
Ironwork..... do.....	1, 000, 000	.07	70, 000.00	
Oak..... feet b. m.....	180, 000	150.00	27, 000.00	
Machinery.....			900, 000.00	
Total locks.....				54, 512, 000.00
Total bridges.....				7, 191, 000.00
Total railroad relocation..... miles.....	28	35, 000.00	980, 000.00	
Earth excavation..... cubic yards.....	2, 300	1.50	3, 450.00	
Rock excavation..... do.....	6, 900	3.75	25, 875.00	
Concrete..... do.....	1, 450	15.00	21, 750.00	

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TABLE No. 38.—*Ship canal proposition—Summary of estimate of construction cost—Continued.*

Item.	Quantity.	Unit price.	Amount.	Total.
Circular tunnel, 12 feet diameter.....linear feet..	2,230	\$125.00	\$279,000.00	
Gates.....	2	11,000.00	22,000.00	
Building.....square feet..	2,250	12.00	27,000.00	
Total main ice run.....				\$379,000.00
Earth excavation.....cubic yards..	215,000	.65	140,000.00	
Rock excavation.....do.....	232,000	1.90	441,000.00	
Dredging rock.....do.....	297,000	6.50	1,930,000.00	
Plain concrete.....do.....	31,800	12.00	382,000.00	
Cribs.....linear feet..	4,350	180.00	783,000.00	
Riprap and rock filling.....cubic yards..	171,000	1.00	171,000.00	
Total Lewiston entrance.....				3,847,000.00
Dredging Niagara Bar.....cubic yards..	470,000	1.25	588,000.00	
Earth excavation.....do.....	246,000	.65	160,000.00	
Rock excavation.....do.....	1,199,500	2.25	4,499,000.00	
Plain concrete.....do.....	73,430	12.00	881,000.00	
Total power canal, intake and forebay.....				5,540,000.00
Earth excavation.....cubic yards..	14,800	.65	10,000.00	
Rock excavation.....do.....	96,100	3.00	288,000.00	
Plain concrete.....do.....	14,800	12.00	178,000.00	
Reinforced concrete.....do.....	750	25.00	19,000.00	
Circular tunnel, 12 feet diameter.....linear feet..	693	125.00	87,000.00	
Gates.....	34	18,000.00	612,000.00	
Do.....	2	11,000.00	22,000.00	
Racks.....pounds..	1,020,000	.10	102,000.00	
Building.....square feet..	70,200	12.00	842,000.00	
Total rack house and ice run.....				2,180,000.00
Circular tunnel, 15 feet diameter.....linear feet..	7,565	156.00	1,180,000.00	
Taper tunnel, mean diameter 13½ feet.....do.....	510	154.00	79,000.00	
Circular tunnel, 12 feet diameter.....do.....	510	125.00	64,000.00	
Total penstock tunnels.....				1,323,000.00
Rock excavation.....cubic yards..	172,000	3.50	603,000.00	
Dredging rock.....do.....	21,300	6.50	139,000.00	
Plain concrete.....do.....	66,770	12.00	801,000.00	
Reinforced concrete.....do.....	660	25.00	16,000.00	
Building.....square feet..	72,000	15.00	1,080,000.00	
Rebuilding Gorge Route tracks.....			4,000.00	
Total power house.....				2,642,000.00
Turbines and generators.....horsepower..	646,000	14.00	9,044,000.00	
Erection and accessories.....do.....	646,000	3.30	2,132,000.00	
Penstocks.....pounds..	2,327,000	.10	233,000.00	
Total equipment.....				11,409,000.00
Real estate.....				1,606,000.00
Summation.....				156,492,000.00
Contingencies, 15 per cent of \$156,492,000.....				23,474,000.00
Engineering and superintendence, 10 per cent of \$156,492,000.....				15,649,000.00
Summation.....				195,615,000.00
Construction interest, 7 per cent of \$39,963,000.....				2,797,000.00
Construction cost.....				198,412,000.00
Cost per horsepower for 611,000 horsepower.....				324.70
Cost per horsepower, excluding navigation features.....				97.50

If the width of the ship canal is reduced to 200 feet, the hydraulic losses are increased to 6.5 feet, which gives a net head of 309.9 feet and a power output of 605,000 horsepower. This is 30.3 horsepower per cubic foot per second and shows an over-all efficiency of 84.2 per cent. The estimated cost is \$170,000,000, which is \$281 per horsepower. If the width is made 400 feet throughout and the depth 30 feet, the cost is approximately \$203,000,000, or \$332.20 per horsepower.

If the locks were reduced to the minimum size necessary to accommodate modern boats, say, 650 feet long, 70 feet wide, and with 25

feet available depth, the cost would be reduced by ten to twenty million dollars.

The time of construction is estimated to be between 8 and 10 years. Power development might begin when approximately two-thirds of the entire work was complete.

The combined ship and power canal, with 300-foot width, is estimated to cost \$19,833,000 more than the sum of the costs of a 200-foot ship canal for navigation only and the power canal proposition described previously. It is estimated to produce 20,000 horsepower more than the power canal project.

It has been suggested that the water diverted from the ship canal into the power canal should be taken from the bottom of the ship canal rather than from the side, as herein planned, in order to relieve navigation of difficulties due to the cross-current. It has been suggested also that a power tunnel rather than a power canal be provided between the ship canal and the power house. It is believed these structures would prove more expensive and less desirable than those adopted for this estimate, but they seem worthy of careful consideration in case construction of a combined ship canal and power development is contemplated seriously.

8. PROPOSED ERIE AND ONTARIO SANITARY CANAL.

The proposed canal of the Erie & Ontario Sanitary Canal Co. has been described in section A, with emphasis on the navigation features, and the sanitary features of the company's project are discussed in section B of this report.

From a purely mechanical point of view there seems to be no insuperable obstacle to the operation of the proposed canal in the summer time. The probability of serious difficulties with ice in wintertime seems very great. Every winter the prevailing westerly winds drive the ice into the narrow eastern end of Lake Erie. From Sturgeon Point to Buffalo the ice is driven high on the beaches, while a vast ice pack, heaped into enormous windrows and ridges, extends offshore as far as the eye can reach. It is from this shore that it is proposed to take 21,000 cubic feet of water per second through the canal.

The estimate of the cost of this project submitted by the company is shown in Table No. 39.

TABLE No. 39.—*Estimate of cost.*

[Submitted by Erie & Ontario Sanitary Canal Co., August, 1918.]

Ordinary earth excavation, main canal, 46,300,000 yards at 15 cents	\$6,945,000
Soft shale excavation, main canal, 59,700,000 yards at 15 cents	8,955,000
Hard shale and limestone excavation, main canal, 60,500,000 yards at 40 cents	24,200,000
Ordinary earth excavation, barge canal, 18,100,000 yards at 15 cents	1,215,000
Concrete in side walls, 230,000 yards at \$6	1,380,000
Railroad tracks, 470,000 linear feet of single track at \$4	1,880,000
Total	44,575,000
Contingencies 5 per cent	2,225,000
Total	46,800,000

TABLE No. 39.—*Estimate of cost*—Continued.

Bridges over main canal (mostly lift) including contingencies.....	\$10,430,000
Bridges over river branch canal.....	708,000
Total.....	57,938,000
High-lift lock, 208 by 650 by 70 by 35 feet, twin steel tanks.....	7,697,000
Low-lift lock, 104 by 650 by 70 by 35 feet, twin steel tanks.....	6,734,000
Total.....	72,369,000
(High-lift lock will operate in 10 minutes, low in 5 minutes.)	
Entrance lock at Lake Erie to regulate level of canal.....	500,000
Seneca Shoal Harbor 4 miles into Lake Erie, made with waste material from excavation and concrete.....	3,000,000
Olcott Harbor.....	1,000,000
Entrance lock at Black Rock, for barges to Tonawanda.....	500,000
Chambers and screens for sewage.....	300,000
Guard lock east of Tonawanda, for barge canal.....	1,000,000
Dam in Eighteen Mile Creek, 5,000 horsepower.....	500,000
Submerged weirs in Niagara River to regulate lake levels.....	150,000
Spreading pier above Horseshoe Falls for scenic grandeur.....	150,000
Power houses.....	1,000,000
Penstocks, turbines, and generators for 800,000 horsepower.....	8,000,000
Transmission and transformers.....	3,500,000
Right of way.....	2,000,000
Two per cent commission sale of bonds.....	2,000,000
Total.....	95,969,000

The quantities of excavation, etc., are satisfactory, but the unit prices are based upon a remarkably large drop from present prices. A revised schedule was prepared to get an estimate of cost of the project which would be more nearly comparable with costs given for the other propositions considered in this report. The item for the cost of a dam in Eighteen Mile Creek was dropped, as was also the item of 5,000 horsepower to be generated there. The promoters are apparently unaware of the fact that this power can be developed only by the use of 500 cubic feet per second of water diverted from the Niagara River as now diverted by the Hydraulic Race Co. of Lockport. This 500 cubic feet per second is part of the diversion authorized by the treaty, and, as the present proposition is to divert all the treaty water through a sanitary canal, no water power of any value would be left in Eighteen Mile Creek. The two items for a regulating weir in the Niagara River and a "spreading pier" above the Horseshoe Falls have been dropped. These are matters properly combined with any new power project, but as they have not been charged against the others they will not be against this one. The items for transformers and transmission, and for commission on the sale of bonds, are dropped as all comparisons in this section have been on the basis of the cost of power at the bus bars, exclusive of promotion and finance. The items of excavation and concrete are charged at the unit prices given in Table No. 28. As hardly a suggestion has been offered as to the proposed layout of the hydroelectric plants, costs for them have been adopted based on similar plants in other propositions. The detailed estimates of the company's engineer on bridges and locks have been carefully studied, and it appears that the unit prices therein adopted must be almost exactly doubled to make them comparable with unit prices used in the power project

estimates previously given in this report. These estimated costs therefore have been doubled, and the remaining minor items for which there is very little data have been doubled also.

The resulting estimate is given in table No. 40. The total cost is \$401,760,000. This is on a basis comparable with the costs of the other propositions discussed in previous paragraphs of this report, although it gives the company the benefit of several doubts and is considered low in comparison with the others.

The company has stated that eventually some economical way of utilizing the power in the 8-foot drop from Lake Erie into the head of the canal may be developed, but its cost is not included in the estimate. Omitting this, and omitting the 5,000 horsepower from Eighteen Mile Creek for reasons stated above, the power output computed on a basis comparable to that of the other propositions falls a little short of the 800,000 horsepower claimed by the company. At mean stage it amounts to 787,000 horsepower, which is 30.3 horsepower per cubic foot per second. On this basis the estimated cost of the development is \$510.50 per horsepower.

In Section F 10 of this report the cost of power production by different projects is estimated. This is for power at the bus bars, exclusive of transmission, promotion, and finance costs, and it ranges between \$10 and \$16 per horsepower-year. Similar computations for the Erie & Ontario Canal scheme give a cost of \$65 per horsepower. It is possible that after business conditions have been stabilized on a peace basis, costs will be much lower than at present, but the benefits will accrue to projects located at Niagara Falls or Lewiston as much as to this one.

TABLE NO. 40.—*Erie and Ontario Sanitary Canal—Revised estimate of cost.*

Excavation :	
Earth and soft shale, 124,100,000 cubic yards at 65 cents.....	\$80,665,000
Rock, 60,500,000 cubic yards at \$1.95.....	117,975,000
Concrete, 230,000 cubic yards at \$12.....	2,760,000
Railroad track.....	3,760,000
Bridges.....	21,260,000
Lift locks.....	23,860,000
Entrance lock, Lake Erie.....	1,000,000
Seneca Harbor.....	6,000,000
Olcott Harbor.....	2,000,000
Black Rock Lock.....	1,000,000
Chambers and screens for sewage.....	600,000
Tonawanda Guard Lock.....	2,000,000
Power houses.....	5,700,000
Headworks.....	3,000,000
Penstocks.....	700,000
Turbines, generators, valves, switch gear, etc.....	18,000,000
Right of way.....	3,700,000
Summation.....	298,980,000
Contingencies, 15 per cent of \$298,980,000.....	44,850,000
Engineering and superintendence, 10 per cent of \$298,980,000.....	29,900,000
Summation.....	373,730,000
Construction interest, 7½ per cent of \$373,730,000.....	28,030,000
Construction cost.....	401,760,000

Cost per horsepower for 787,000 horsepower is \$510.50.

9. PLANTS PROPOSED BY VARIOUS INTERESTS.

From time to time a great many schemes for Niagara power development have been submitted to the War Department for approval. Most of these follow the lines laid down in Sections F-3 to F-7, inclusive, of this report. All which appear to have value will now be discussed briefly. The absurd and freakish schemes, such as the proposal to establish overshot paddle wheels in a cave dug behind the Falls, will not be dealt with.

Propositions of Hydraulic Power Co.—In February, 1918, the Hydraulic Power Co. of Niagara Falls submitted four power propositions to the division engineer. The first two, which were named "Proposition H. P.-A," and "Proposition H. P.-B," contemplated an extension of the existing plant to utilize 9,500 cubic feet per second, altogether, under a head of about 212 feet, about 60,000 or 65,000 new horsepower being produced. The present Hydraulic Canal was to be somewhat enlarged. "Proposition H. P.-C" was practically the same as the upper stage part of the "compound 2-stage proposition," described in Section F-5. "Proposition H. P.-D" was practically the same as the whole "compound 2-stage proposition." The cost and power output of these developments would be about the same as for the "compound 2-stage proposition." Comment on the upper stage portions of these propositions was made in the interim report.

Propositions of Niagara Falls Power Co.—The Niagara Falls Power Co. submitted two projects in February, 1918. "Proposition F-4" of this company was for the use of 10,260 cubic feet per second in a tailrace tunnel development similar to the one treated in Section F-3, but operating only on the upper stage. The possibility of enlarging this proposition to a capacity of 20,000 cubic feet per second was mentioned. This plan was discussed in the interim report and the conclusion reached that it would take longer to develop, was more expensive, and was less efficient than proposition H. P.-C of the Hydraulic Power Co.

The other proposition of the company, "K-4," was for a canal to utilize 20,000 cubic feet per second under the full head. In its general outline this corresponds to the canal project in Section F-3. Its cost and power output would be similar. Studies of power canals proposed for this locality have shown that the comparatively wide and shallow canal, with concrete-lined bottom, which this plan proposes, is less economical for this location than a narrower, deeper, unlined section.

Propositions of the Empire Power Corporation.—In February, 1918, the Empire Power Corporation submitted a proposition for developing power with a diversion of 4,400 cubic feet per second on the upper stage. The scheme was to take water from Niagara River just below Port Day into a canal along the shore of the New York State Reservation, conducting it to a point opposite the head of Goat Island. Here it was to enter two 17-foot concrete conduits running under the reservation to a power house on the present site of the International Hotel buildings. The power house was to have turbines and generators situated in a deep pit, much as in the present power houses of the Niagara Falls Power Co. From the power house a tailrace tunnel was to take the water to an outfall about

500 feet upstream from the International Bridge. The objections to the scheme were stated in the interim report of March 2, 1918.

In April, 1915, the Empire Power Corporation submitted a second proposition. This was a scheme to utilize a diversion of 13,000 cubic feet per second along the lines of the first proposition of this company. The canal of the earlier scheme was retained, but was closed at the upper end, thus forming a sort of fore bay. A large boat-shaped intake in Niagara River is provided, about 1,500 feet south of the plant of the International Paper Co. Entering this and passing through the racks the water plunges downward into a tunnel. Passing horizontally for about 2,300 feet through this tunnel it rises again into the fore bay. From the fore bay it goes underground again through three conduits to two power houses similar to those of the earlier project, and is discharged through a tailrace tunnel at the same outfall.

Propositions of Hugh L. Cooper & Co.—On January 5, 1918, Hugh L. Cooper & Co., consulting engineers, of New York City, submitted to the division engineer 19 different propositions for developing power at Niagara Falls.

Plans A, B, and C were for tailrace-tunnel developments of the lower stage, with diversions of 41,360, 30,980, and 20,600 cubic feet per second, respectively. They provide for a power house in the talus slope of the gorge about 500 feet above the Michigan Central Railway bridge, and a straight tailrace tunnel discharging near the Devils Hole. The reasons given in Section F-5 for avoiding plants taking water from the Maid of the Mist pool all apply in full force to these three plans.

Plans D, E, F, and W are for tailrace-tunnel projects developing the upper stage, with diversions of 33,000, 23,000, 13,000, and 10,500 cubic feet per second, respectively. In general these resemble the plan of the Niagara Falls Power Co., but the design and location of the power house seem somewhat less satisfactory, especially in the matter of protection from ice.

Plans G, H, X, and I are for a pressure-tunnel development of the full head of both stages, using 33,000, 23,000, 20,000, and 13,000 cubic feet per second, respectively. The intake behind Connors Island seems very much exposed to ice troubles. The large open fore bay at the brink of the lower gorge seems expensive and inefficient as compared with a differential surge tank. There appears to be no sufficient reason why the water in the tunnel at elevation 345 should be raised to elevation 530 and then lowered to elevation 345 again through expensive steel penstocks. The subterranean power house appears unduly crowded and expensive. Otherwise these propositions stand on the same basis as the headrace-tunnel plant of Section F-3.

Plans J, K, Y, and L are for the same diversions used under the full head by means of a canal. The same power-house design is used as in Plans G, H, X, and I. The present investigation has shown that a more economical location for the canal can be found farther west, that a more economical cross-section of canal is obtainable and that better protection from ice can be provided.

Plans M, N, Z, and O are for the same diversions and head developed by a tailrace-tunnel project. Except for the cramped power

house and inferior ice protection, the scheme is about equivalent to the tailrace-tunnel proposition in Section F-3.

Plan Z was recommended provisionally, subject to very thorough examination of the rock along the tunnel route by drilling or otherwise. Plan Y was recommended for adoption in case the rock proved unsuitable for tunneling.

Propositions of Mr. L. H. Davis.—Ten schemes for Niagara power development, submitted to the Union Carbide Co. by Mr. Leonard H. Davis, of Sault Ste. Marie, have come to the War Department. These all provide for the use of 19,500 cubic feet of water per second, under the full head, in one or more stages. Of these schemes, which are set forth in reports dated March 1 and April 1, 1918, he recommends schemes 5-b and 4 as the best. Scheme 5-b is practically identical with the canal proposition of Section F-3. The only differences are that the canal intake is behind Conners Island, where ice troubles would be greater than out in front of it, as in F-3, and that the canal location and cross-section are not quite as economical as the ones described in F-3.

Scheme 4 is a rather complex affair. The Hydraulic Power Co.'s plant is retained, a tunnel 29 feet in diameter, with an intake above the railroad bridges, taking the 9,500 cubic feet per second, assumed ultimately to be used by this plant, extends to a power house below the Riverdale Cemetery. A canal 61 feet wide and 30 feet deep carries 11,000 cubic feet per second from behind Conners Island to the same new power house. This project is inferior to 5-b, and is also inferior in general layout to the compound two-stage proposition.

Scheme 5-a is the canal scheme with the power house moved down to Lewiston, greatly increasing the cost and slightly decreasing the production of power. Scheme 5-c is the headrace-tunnel proposition in its usual form. Schemes 1, 2, 3-a, and 3-b are ingenious attempts to utilize the present power plants as part of a full-head development. By Mr. Davis's own statement, the results are inferior to schemes 4 and 5-b. In addition several of them would involve a great temporary curtailment of the present power output, which is inadmissible.

Proposition of the Niagara Gorge Power Co.—A project of the Niagara Gorge Power Co., designed by Barclay, Parsons, & Klapp, consulting engineers, was submitted by the power company to the Secretary of State, in an application for a permit to divert 20,000 cubic feet of water per second from the Maid of the Mist pool. The Niagara Gorge Power Co. is controlled by the same interests as the Niagara Gorge Railway Co., owner of the electric railway in the gorge. In the plan of Messrs. Barclay, Parsons & Klapp an intake is provided between the railroad bridges at the foot of the Maid of the Mist pool. From the intake the water flows through a pair of 33-foot tunnels to a power house under the transmission-line crossing. The location of the intake, determined by ownership of the site, is, as regards interference and damage from ice, subject to all of the objections made in section F-5 to intakes in the Maid of the Mist pool.

Proposition of T. Kennard Thomson.—A proposition of Mr. T. Kennard Thomson, consulting engineer, of New York City, was re-

ceived in January, 1918. The engineering features are very meagerly described in the folio submitted. Additional facts have been gathered from an article by Mr. Thomson, which was reprinted in the Niagara Falls Journal, August 22, 1917. The scheme provides for a dam in the gorge at the foot of Fosters Flats, which will cause the water to rise and obliterate Fosters Flats Rapids and the whirlpool. The whole flow of the river is to be used to generate 1,000,000 horsepower or more.

Miscellaneous propositions.—The Niagara County Irrigation and Water Supply Co. proposes to utilize 4,400 cubic feet per second by a canal from La Salle to the Devils Hole. The route recommended is uneconomically long and the power in a fall of 9 feet in the rapids below the Devils Hole is lost.

Another proposition was that the State of New York and the city of Niagara Falls unite in developing 4,400 cubic feet of water per second in a project similar to that of the Empire Power Corporation, except that the power house was to be in a cave, excavated under the reservation. The scheme had no particular merits.

10. COMPARISON OF PROPOSED DEVELOPMENTS.

Certain remarks which apply to several of the proposed schemes for power development have been reserved for this part of the report.

For convenience of reference and comparison Table No. 41 is here presented as a statistical summary of estimates previously given. In it are the name, quantity of diversion, gross head, net head, horsepower per cubic foot of water per second, total horsepower produced, construction cost per horsepower, and time of development for each project which provides a complete working plant. In regard to these estimates it seems proper and important to repeat that they are preliminary estimates based on outline layouts which can in no sense be considered final designs. While a great deal of study, thought, labor, and care have been expended upon them, they have not been, and under the circumstances could not be, based on careful consideration of the multitudinous lesser details. Indeed, so many essential elements are unavoidably of such uncertain character that any further refinement appears without justification for the purposes of the report. It is believed that they are sufficiently sound and correct to be used without hesitation in the consideration of the important problem to which they apply.

There is a possibility that the intakes on Grass Island Shoal provided in several of the propositions would have to be located farther toward midstream in order not to pass ice into the new intake channel of the Hydraulic Power Co. or else new piers and booms might have to be provided for that company and some dredging done on the rock shoal upstream from Goat Island. In either case an important item would be added to the construction cost of the proposition involved. The pressure tunnel location under Sugar Street and the power canal intake south of Conners Island are free from this possible objection.

In the descriptions of generating machinery provided for the various propositions individual exciters have been specified, mounted on the generators. This was done because the prices furnished by

manufacturers of generating machinery were based on such designs. It is not intended to specify any such minor detail in the sense of advocating it in preference to another design equally good or better. The exciter system of the Ontario Power Co. or that of the Mississippi River Power Co. is probably a little better. These involve one or two separate hydroelectric service units in each power station, and presumably are somewhat more expensive to install than the system specified. The difference in expense would apply about equally to all single-stage propositions and would affect the two-stage propositions slightly more.

It will be noted that in Table No. 41 none of the power-development schemes which involve a reasonably low capital cost are credited with an output as great as 30 horsepower per cubic foot of water diverted per second from Niagara River. Any one of them utilizing the gross head from Grass Island to Riverdale Cemetery can be made to produce 30 horsepower per cubic foot per second at added expense. This would involve an increase in rates or a diminution in return to the investors in the enterprise. The power-canal proposition can be brought up to this output at less expense than the other propositions.

TABLE 41.—*Summary of comparative estimates of various development projects.*

[Omissions and assumptions as in accompanying text.]

Proposition, number, and name.	Total diversion, cubic feet per second.	Gross head.	Net head.	Total horsepower on bus bars.	Horsepower, per cubic foot per second.	Construction cost. ¹	Construction cost, per horsepower. ¹	Time of development (years).	
								First power.	Complete.
1. Power canal.....	20,000	313.8	302.8	591,000	29.6	\$43,579,000	\$73.70	2½	5
2. Pressure tunnel.....	20,000	312.6	301.8	588,000	29.4	50,803,000	86.40	3	5
3. Tailrace tunnel.....	20,000	312.6	299.0	584,000	29.2	52,220,000	89.40	3	5
Simple two-stage.....	20,000	312.2	297.5	580,000	29.0	61,227,000	105.60	2	4½
Upper stage only.....	20,000	215.2	208.2	406,000	20.3	31,528,000	77.70	2	4½
Lower stage only.....	20,000	97.0	89.2	174,000	8.7	29,699,000	170.70	2	4½
5. Compound two-stage.....	20,000	312.0	298.4	573,000	28.6	55,481,000	96.80	1	4½
Upper stage only.....	20,000	219.0	214.4	406,000	20.4	21,183,000	51.80	1	3½
Lower stage only.....	20,000	93.0	84.0	164,000	8.2	34,298,000	209.10	2½	4½
6. Ship canal:									
300 feet wide, 40 feet deep.....	20,000	316.4	312.9	611,000	30.6	136,412,000	324.70	7	10
400 feet wide, 30 feet deep.....	20,000	316.4	312.9	611,000	30.6	203,000,000	332.20	7	10
200 feet wide, 38 feet deep.....	20,000	316.4	309.9	605,000	30.2	170,000,000	281.00	6	9
Portion of works of 300 foot canal necessitated by the power development.....						93,000,000	97.50	7	.....
7. Erie and Ontario Sanitary Canal.....	26,000	326.4	310.2	787,000	30.3	401,760,000	510.50	.....	.....

¹ See text for assumptions and omissions.

In line with the remarks in the preceding paragraph, and in further explanation of statements in Section F-1 of this report regarding economic sizes of main conduits, it may be noted that the most economical diameter of long tunnel for the tailrace tunnel, pressure tunnel, and two-stage propositions on the basis of the finally assumed unit costs, fixed charges, and selling price of power is 43 feet instead of 48 feet, as adopted. Use of the smaller tunnel would decrease the

construction cost of the pressure-tunnel proposition about 8 per cent and reduce the power output a little more than 2 per cent. The construction cost per horsepower produced would be reduced approximately $6\frac{1}{2}$ per cent. This brings the cost per horsepower of the pressure-tunnel proposition more than one-third of the way down to the corresponding figure for the power-canal proposition, but decreases the available power output by 14,000 horsepower. The basis on which the various propositions were compared, as defined in the assumptions stated in Section F-1, was not the production of equal amounts of power from equal quantities of water, but the use in each case of 20,000 cubic feet of water per second to produce as much power as was consistent with good economy of development. At the same time it was considered wise to increase main tunnels and canals somewhat beyond the size demanded by present-day economy to prevent falling into a difficulty similar to that now confronting the plant of the old Niagara Falls Power Co. In so doing it has come about that the total amounts of power provided by the various propositions do not differ very widely.

Another point in this connection is the situation with respect to the location of the power house in the lower gorge. For best economy of investment the power house of the power-canal proposition should be located where shown, abreast of Riverdale Cemetery. To move it either up or down stream economy must be sacrificed. With respect to all the tunnel propositions, however, the economy would be slightly improved by locating the downstream terminus near Devils Hole. Nine feet of head would thus be sacrificed, representing a large amount of power. The Devils Hole site was avoided to prevent such sacrifice of available power, and at the same time to make the tunnel and canal propositions more nearly comparable.

The costs given in the preceding parts of Section F and in Table No. 41 covering the various projects considered, do not include the entire capital costs nor even the whole of what might be termed construction costs. Thus the general overhead items, properly part of construction costs, which have been omitted in each case, are costs of promoting interest in the proposition, of obtaining funds, of organizing a managing company, and of legal services involved in promotion, financing, and organizing. The fundamental item of purchase of any necessary rights from existing power companies has not been included. The development expense involved in building up a market for power consumption and making the enterprise a going concern, also properly a part of capital cost, has been omitted. The costs given are called construction costs. They include purchase of necessary land and rights of way and construction required in providing a plant to produce electric energy at generator voltage on the bus bars of the power station. All expense pertaining to transformation and transmission of electric energy has been omitted purposely.

The omissions just mentioned have appreciable effects on the capital cost of each proposition, and since these effects are not equal on the different projects, it becomes desirable to note them and discuss them briefly. Furthermore, in the matter of operating costs there are almost certain to be differences worthy of consideration; and, if so, these should be taken into account in studying the desirability of the different schemes. An estimate has therefore been made of the cost of producing power in each case.

Any one of the seven propositions listed in Table No. 41, which covers the full head, might be adopted as the final plan for utilizing the full 20,000 cubic feet per second of diversion now permissible under the treaty with Great Britain. Under any of these plans some or all of the existing plants would be superseded. Whether or not the companies now diverting water from the Niagara River have any rights to such water beyond the revocable ones granted by their permits from the Secretary of War, and whether any new company desiring to use this water would have to compensate them is considered to be a question outside of the scope of this report.

It is essential, however, that the effect of these rights, if any exist, upon the cost of producing power by the various propositions to be compared be taken into consideration, as it has an important effect upon the relative economy of the different propositions. For this reason, the comparison will be worked out under two different assumptions. First, it will be assumed that the companies now using water possess a right therein that can not be taken from them without equitable compensation. Under this assumption the cost of producing power from the authorized diversion of 20,000 cubic feet per second by each of the propositions will be compared. Matter relating to this comparison will be referred to as based on "the use of the first diversion of 20,000 cubic feet per second." Secondly, it will be assumed that by a new treaty an additional diversion of 20,000 cubic feet per second has been authorized. This could be developed without interfering with the existing plants and without expense for acquiring any rights which the existing companies may claim to possess. The comparison of costs of power production under this second assumption will be referred to as based on "the use of the second diversion of 20,000 cubic feet per second." If it be found, as a matter of fact, that the power companies have no rights of any kind for the deprivation of which they would be entitled to compensation, the comparative costs computed for the second diversion of 20,000 cubic feet per second would apply also to new plants built to utilize the diversion authorized by the existing treaty.

The power outputs listed in Table No. 41, and used in deriving the construction costs per horsepower, as given in the same table, are the outputs which would obtain with plants in first-class condition, operating at best efficiency, with the river at mean stage, and using in each case the full quantity of water listed under total diversion.

As regards variation of power with stage, the situation at Niagara is almost ideal. The full supply of water up to any total diversion contemplated is available at any stage of the river which occurs, and can be diverted for power development except in extremely rare cases of very bad conditions. The head varies a little with changes of stage, the variation in water level in the Maid of the Mist Pool being in the same direction and about four times as great as in the Chippawa-Grass Island Pool. Accordingly, at high stage the available head is less than at mean stage and the possible power output correspondingly less, conditions being reversed at low stage. It is only once or twice a year that this variation amounts to as much as 1 per cent.

The assumption of full power output, and full continuous diversion of the maximum amount of water permitted, is in accordance

with common practice when comparing construction costs per horsepower. Such an output would not, of course, be obtained in actual operation, and the construction cost per horsepower of actual average output would be greater than that given, depending in amount on the output.

In estimating operating costs it has seemed best to assume a power output in each case such as it is believed would exist after the plant was fully constructed and the market built up to capacity. The ratio of average power delivered to maximum power delivered is known as the load factor. The situation at Niagara Falls is unique in respect to the load factors which prevail. At the plant of the Hydraulic Power Co. it is probably nearer unity than at any other large plant in the world, the daily load factor ranging from 90 to 99 per cent. At the plant of the Niagara Falls Power Co. it is much lower, but still unusually good. A load factor of 60 per cent is well above the average in central station practice. The reason for the high-load factors at Niagara Falls is the fact that the load is consumed largely by electrochemical plants operating continuous processes, 24 hours a day, 7 days a week. These industries are the ones which benefit most from cheap power, and most of them are actually dependent upon it for existence. There are many reasons for believing that the future market developed in this vicinity will consist largely of loads of similar character, and accordingly it has been assumed that 90 per cent of the full power production possible at mean stage will be marketed continuously. The power production costs are based on this assumption.

The marketable power production of a plant which is limited as to its supply of water depends to a slight extent upon the power factor of the connected load, and the production cost depends even more on the power factor. For a plant as a whole the power factor may be defined as the ratio of output in kilowatts to output in kilovolt-amperes. Niagara loads are very good in this respect also, the power factors averaging close to unity because of the character of the connected loads. An important consideration being the use of many synchronous converters whose fields may be overexcited to keep this factor near unity. The generators provided in the estimates are designed with ample windings to permit full turbine capacity to be developed with the power factor at 90 per cent. At this value the reduction in the amount of marketable power available is too light to be considered. Because of the extra copper in the generators, however, and the extra size of the generator thereby required, the capital costs, and hence the annual charges, are increased.

The estimates of cost of producing power probably are not as accurate as the construction cost estimates, being based on less reliable data and having been prepared with far less care. As already pointed out, they are probably several dollars per horsepower per annum less than the ultimate actual cost of delivering power on the premises of any customer because of the cost items omitted. They should be regarded as rough estimates, believed to be sufficiently good to form a fair basis of comparison of the various propositions. Production costs include fixed charges and operation charges, which latter include salaries of most of the employees, cost of supplies, and cost of

maintenance. Maintenance includes repairs and minor or frequent replacements. Fixed charges were assumed at 10 per cent per annum of the total construction costs, being divided as follows: Interest on investment, $5\frac{1}{2}$ per cent; depreciation, $2\frac{1}{2}$ per cent; taxes and insurance, 2 per cent. The operation costs were computed in each case.

As regards fixed charges, a few general remarks seem desirable. A rate of interest of $5\frac{1}{2}$ per cent was considered best for these estimates. It is evident that the rate will depend to a large extent on the credit of the organization handling the enterprise. Thus if it were undertaken by the United States Government, funds might be readily raised at 4 to $4\frac{1}{2}$ per cent on Government bonds based on the property and guaranteed by the Treasury Department.

At Niagara Falls a water-power development is far less speculative, and it seems likely that financing would be less difficult, than under average conditions. On a normal money market a private company might be able to finance such a proposition at rates varying between 5 and 7 per cent, depending on the resources and character of the men in charge. The rate of $6\frac{1}{2}$ per cent adopted in these estimates was a mean of the various possible cases considered.

Depreciation has been taken at $2\frac{1}{2}$ per cent per annum on the whole construction cost with the thought that a depreciation reserve will be established to care for retirement of property items which have become inadequate or obsolete or which require replacement because of accident, use, or age, the funds representing the balance of the reserve being at all times readily available for replacements, in order to preserve the integrity of the total investment unimpaired.

It is understood that a proper annual depreciation allowance to cover hydraulic and electric machinery ranges from 4 to 8 per cent. Something like half the cost of construction of these propositions, however, is for works whose rate of depreciation is likely to be so low that 1 per cent per annum of the construction cost set aside at 5 per cent compound interest would seem ample to care for it. Another portion of the works amounting to more than one-quarter of the total construction cost might be cared for by a 2 per cent annuity similarly set aside. For the average expected service life an annual rate of $2\frac{1}{2}$ per cent has seemed about right. This is based on the compound-interest method of depreciation accounting as applied to individual items of the property.

Two per cent per annum of the construction cost is believed to be sufficient to cover both insurance and taxes, including fire and liability insurance and property and war taxes. Since it has been assumed in these estimates that gross income is just sufficient to maintain and operate the plant there is no net income, and hence no income tax to care for. War taxes include only excise, utilities, insurance, and stamp taxes and amount to a very small sum comparatively.

Several engineers were found to be agreed that 10 per cent was about right for fixed charges, and it is believed the assumption is sufficiently correct even though the subdivision of the total into its parts is not as well worked out. It is to be noted that the matter of fixed charges is very important in its effect both on annual production charges and on construction costs. Thus fixed charges constitute two-thirds or more of the annual production charges. They also influence construction costs because they form the most in-

fluent factor in the determination of the economic sizes of various portions of the plant.

In computing operation charges an estimate was made of the positions to be filled and the probable salaries required. To the annual sum covering salaries 40 per cent was added to cover supplies and sundries. An estimate was then made of the annual cost of repairs and minor replacements. This latter figure was based on such information as came to hand. In each case the figure for repairs and minor replacements is much the same as the figure for salaries and supplies. As already stated, it is believed the estimated operating charges as presented give a reasonable idea of what might be expected. They seem to compare properly with other estimates and known costs. An engineer well acquainted with power-plant operation at Niagara Falls stated that it was impossible to forecast within limits of any value the operation costs of a plant so much larger than and different from any yet constructed. It seems, on the other hand that it is of importance to know that they are likely to be more than \$1 per horsepower year and less than \$4. As a matter of comparison among the different propositions the figures given are believed to be very fair.

For the sake of clearness and simplicity first consideration will be given to the case that might arise after the companies at present operating were fully cared for and were utilizing the 20,000 cubic feet per second of water provided in the present treaty. If then an additional 20,000 cubic feet per second of water was to be developed under one of the first four propositions listed in Table No. 41, the operation costs and annual charges for horsepower would be as in Table No. 42.

TABLE No. 42.—*Estimated annual charges for power development, exclusive of fixed charges on original overhead and development expenses.*

[Based on use of a second diversion of 20,000 cubic feet per second.]

No.	Proposition.	90 per cent of maximum continuous output, in horsepower.	Fixed charges per horsepower per year.	Operation charges per horsepower per year.	Cost of power on bus bars per horsepower per year.
1	Power canal	532,000	\$8.20	\$1.80	\$10.00
2	Pressure tunnel	529,000	9.60	1.70	11.30
3	Tailrace tunnel	526,000	9.90	1.70	11.60
4	Simple two-stage	522,000	11.70	2.20	13.90

Under the conditions noted, this power would be sold to new plants which would preferably be located as near as possible to the new power houses. Transforming and transmission costs would be the same for all four propositions, except that the tailrace-tunnel proposition would be somewhat handicapped by the fact that there are fewer available factory sites near it than near the others.

The question of the most economical method of utilizing the present authorized diversion of 20,000 cubic feet of water per second under the assumption that the companies now using this diversion must be compensated if it is taken away from them will now be taken up. The best way to care for the Pettebone Cataract Paper Co.,

Cataract City Milling Co., and Lockport interests would seem to be to compensate them for the loss of the water by providing a suitable supply of electric power at very low rates and under favorable conditions of contract. In case the new power plants do not have a transmission line to Lockport, power might be purchased from the Niagara, Lockport & Ontario Power Co., and resold to plants at that place at rates which would protect those interests from loss. The cost of providing such compensation for all these interests is very uncertain, the matter being a complex one. In order to have something to go by, it will be assumed that the Pettebone interests are supplied 3,000 horsepower, at \$7 per horsepower per annum, the power costing the generating company \$16 per horsepower per annum to provide, and making the net cost to the generating company \$27,000 per annum. Similarly, it will be assumed that 10,000 horsepower is furnished Lockport interests, at \$10 per horsepower per annum, the power costing \$22 per horsepower per annum, or a net amount of \$120,000 per annum. On these assumptions the total cost of compensating the Pettebone and Lockport interests will be \$147,000 per annum.

The new proposition must also, under these assumptions, be charged with paying a just return to the present Niagara Falls Power Co. to compensate for destroying assets of that company. This is another item which at present seems absolutely indeterminate. As a basis for arriving at it a complete inventory of the property would first have to be made, and all tangible and intangible items concerned carefully appraised. It is thought that this charge should not apply to such properties of the present company as transformer houses and equipment, transmission lines, railroads, real estate held for development, and foreign and domestic power plants or distributing plants owned. It should include generators, switch gear, conductors, and electrical accessories, owned by the Aluminum Co. of America, and the Cliff Electrical Distributing Co., in so far as they form component parts of the present power plant.

In explanation of the exclusion of transformer houses, transmission lines, distributing plants, etc., it may be stated that the assumption was that electric power would be sold to the Niagara Falls Power Co. at a price sufficient to permit it to operate its transformers, transmission and distributing system, supplying its present customers, and receiving a fair return upon the fair value of this portion of its plant.

Under the assumption stated above the charge for compensation would properly cover all fixed annual charges against those portions of the physical property of the Hydraulic Power Co. and old Niagara Falls Power Co. now used as parts of hydroelectric plants, but made partially or wholly unserviceable under the new scheme, to the extent that these charges could not be met by other uses or disposition of the properties. In addition, it appears that some compensation might justly be required for intangible values, including, to some extent, the present opportunity of the company for profit. If the new project was allotted to the present company the opportunity for profit thus afforded might well be held to replace the lost opportunity. The following figures were computed from data given in Moody's Manual for 1918, in order to give certain information

for the Hydraulic Power Co., Cliff Electrical Distributing Co., and old Niagara Falls Power Co., combined, for the year 1917:

Gross income.....	\$6, 204, 837
Operating expenses, taxes, and insurance.....	2, 607, 878
Interest.....	1, 377, 260
Available for depreciation, surplus, and dividends.....	2, 219, 699

The gross income given is from all sources. The expenses cover transmission systems, transformer buildings and equipment, and real estate not essential to the plant as a power-producing enterprise. Proper division between the items which are essential and those not essential to the power-producing enterprise is impossible with the data at hand, and doubtless would be considered impossible by the companies themselves with all the data at their command. It will be assumed that a sum of \$2,000,000 per annum is a proper compensation to the present Niagara Falls Power Co.

In the case of the compound two-stage proposition, part of the plant of this company is retained. Of course, fixed charges on this must be included in the final cost of power development. While the distribution of cost would differ in minor details in this case the differences would be small and because of the great uncertainty involved the same figure of \$2,000,000 per annum will be used in this case also.

Table No. 43 is based on the assumptions enumerated in the preceding paragraphs.

The present customers of the existing plants will very likely be retained, and the present transforming, transmitting, and distributing equipment utilized to its full extent. In each case more than 100,000 horsepower must be transmitted between the present plants of the Hydraulic Power Co. and old Niagara Falls Power Co. No allowance has been made for the cost of this item. It is thought the expense might be moderate if the necessary cables were placed in the discharge tunnel of the Niagara Falls Power Co. This cost item does not affect the comparison between plants, as it applies equally to all. For the power canal and pressure tunnel projects the present output of the existing plants, about 250,000 horsepower, would have to be transmitted from the lower gorge up to the present milling district. From the best data available it is estimated that the yearly cost of this service would not exceed \$350,000, and that the power loss would not exceed 8,000 horsepower. This would increase the annual cost per horsepower from \$14 to \$14.90 for the power canal proposition, and from \$15.40 to \$16.30 for the pressure tunnel proposition, as shown in the last column of Table No. 43. Matters of promotion, finance, etc., may be assumed the same in all cases, and so not to affect the validity of the final comparison.

As regards the effect on capital cost, and consequently the effect on fixed annual charges, of cost promotion, financing, organization, development of market and going concern, there is a point worthy of note. In either of the two-stage propositions the cost of the upper stage development is only about one-half of the total cost, while the upper plant produced more than two-thirds of the total power. Moreover the first power could be produced sooner in the two-stage than in the single-stage development; and commencement on construction of the main tunnel could be longer delayed, because the upper stage plant would be able meantime to supply the growing market. The result is that far less unproductive investment is carried at any time

with a two-stage than with a single-stage development, and the capital cost per horsepower produced is less until the projects near completion. This condition would lead to better credit and a sounder financial condition during the construction period, which in turn might make possible the flotation of bonds on better terms.

Thus far in the discussion the production cost only has been dwelt upon. A chance for profit is necessary in such an enterprise in order to induce business men to undertake the risk of running the business and to spur them to the endeavors likely to bring it success. In fact, experience teaches that a speculative profit not only is necessary for inducing the highest degree of managerial efficiency, but is considered essential by investors as a "margin of safety" on bonds to hold up their value and thus prevent increase in effective interest rate. A reasonable profit is a proper assumption. It seems to be a fact that owners of a company are more willing to reinvest earnings in the company's capital than to borrow, although strictly the cost of such capital is the same in either case. The two-stage plant would begin to sell power much sooner than the single-stage plant, and such profit as was derived from these sales would represent an accumulation of capital not available to the single-stage plant. If selling prices were so adjusted as to yield a satisfactory profit after the plant was completed, then the margin would be still greater during the first few years in the case of the two-stage project because of the lower capital cost and consequent smaller fixed charges per horsepower on the upper-stage plant. In addition to swelling profits and lessening the cost of financing a project, an increase in the selling price of power has an influence on construction cost by modifying the economic sizes of conduits and other plant items. Thus, while an increase in selling price per horsepower year adds to the annual income, it at the same time adds to the value of power lost in conduits, etc. An increase in size of conduits will diminish the power loss at the expense of the fixed annual charges. The extent of the increase in size economically justifiable under the new conditions is determined by the principle that the sum of annual fixed charges plus annual value of power lost shall be a minimum. Were competition likely to force selling prices down to cost, the economic sizes would necessarily be based on a minimum cost of producing power consistent with the scope of the proposition adopted.

TABLE NO. 43.—*Estimated annual charges for power development exclusive of development expense and original overhead expense on new portion of plant.*

[Based on use of first diversion of 20,000 cubic feet per second.]

No.	Proposition.	90 per cent of maximum continuous output, in horsepower.	Annual charge, present plant of Niagara Falls Power Co.	Annual charge, Pettebone and Lockport interests.	Ordinary fixed charges per horsepower per year.	Fixed charges on present plant per horsepower per year.	Operating charges per horsepower per year.	Cost of power on bus bars per horsepower per year.	Cost corrected to equalize distribution conditions.
1	Power canal.....	532,000	\$2,000,000	\$147,000	\$8.20	\$4.00	\$1.80	\$14.00	\$14.90
2	Pressure tunnel.....	520,000	2,000,000	147,000	9.60	4.10	1.70	15.40	16.30
3	Taifrace tunnel.....	528,000	2,000,000	147,000	9.90	4.10	1.70	15.70	15.70
4	Simple two stage.....	522,000	2,000,000	147,000	11.70	4.10	2.20	18.00	18.00
5	Compound two stage.....	516,000	2,000,000	147,000	10.70	4.10	2.20	17.00	17.00

An important factor in the determination of the most suitable power-development project for Niagara Falls is the matter of rate of absorption of the power produced. The estimates heretofore given were all made while the war was in progress, and it appeared almost certain that any power developed at Niagara Falls would be absorbed as rapidly as it could be produced. There was one request for 700,000 horsepower in a single block. Accordingly the rate of construction assumed was what might be termed rush-work rate, and the power was supposed to be absorbed as fast as available. If the power was absorbed less rapidly, however, construction interest would increase, and the increase would be greater in the single-stage than in the two-stage plan, largely because, in the latter case, development of the second stage could be delayed a longer time. A larger proportionate number of horsepower hours would be sold during the first few years from the two-stage than from the single-stage plant, the ratio increasing as the rate of absorption decreased.

Table No. 44 has been prepared to show the different rates of construction interest for the various propositions based on two widely different rates of absorption of power. The high rate of absorption is that assumed in the original computation in each case. For the power-canal proposition, for example, it was 243,000 horsepower at the end of two and one-half years and 139,000 horsepower each year thereafter until completion. The low rate of absorption of power assumed was 15,000 horsepower first absorbed at the same time as the first power in the other case, and a uniform rate of 60,000 horsepower per annum thereafter until completion of the plant. Rates of construction interest are on the entire construction cost, less interest, as given in the estimate summaries.

TABLE NO. 44.—*Rates of construction interest, showing variation with change in rate of absorption of power.*

No.	Proposition.	Total cost, less construction interest.	Rate of construction interest.	
			At originally assumed rate of power absorption.	At power absorption rate of 60,000 horsepower per year.
1	Power canal:		<i>Per cent.</i>	<i>Per cent.</i>
	First 20,000 cubic feet per second.....	\$40,351,000	8	18
	Second 20,000 cubic feet per second.....	40,351,000	8	19
4	Simple two-stage:			
	Upper stage only.....	29,485,800	7	14
	Lower stage only.....	27,499,000	8	11
5	Compound two-stage:			
	Upper stage only.....	20,174,000	5	8
	Lower stage only.....	31,466,000	9	11

What a hydroelectric generating station has to sell is electric energy, and this is a capacity to do work. Rate of work is expressed customarily in horsepower or in kilowatts, and electric energy in kilowatt hours, horsepower hours, or horsepower years. The revenue depends, of course, somewhat on the form of selling contracts, but in general it is fair to assume that the ultimate amount of revenue depends very largely on the number of kilowatt hours produced.

The two-stage proposition has an advantage, during the first few years after construction is commenced, over the single-stage proposition, because power is produced so much sooner. As time goes on, however, the total production by the single stage overtakes and surpasses that by the two stage. The first 20,000 cubic feet per second development has a considerable advantage over the second in that power will continue to be produced by the present plants until the time the water is needed for the new stations. This early advantage of the two-stage proposition is larger, and continues longer, when the rate of construction and rate of power absorption are low. Thus at the originally assumed rate of power absorption the total power production by the power canal proposition overtakes that by the simple two-stage proposition in $3\frac{1}{2}$ years after commencement of construction, and thereafter is greater, its advantages continuing to increase slightly.

At the 60,000 horsepower rate of absorption the point of equality is reached in $42\frac{1}{2}$ years. It is perhaps somewhat more correct to compare the propositions on the basis of total amount of energy produced per dollar of construction cost. On this basis the power canal proposition overtakes the simple two-stage proposition in $3\frac{3}{4}$ years at the original rate of power consumption, and in $7\frac{1}{4}$ years at the 60,000 horsepower per annum rate of absorption. In point of power production per dollar of construction cost the power canal proposition overtakes the compound two-stage proposition at the high rate of absorption of power in $2\frac{3}{4}$ years, and at the low rate of absorption in $9\frac{1}{2}$ years. The whole comparison is very unstable, depending upon the estimates of cost of construction and time of construction, a very important factor being the estimate of length of time taken to produce first power in each case. The computations which were made and the curves which were plotted while studying this matter indicate definitely that on the assumptions of the estimates the power canal proposition is considerably superior to the simple two-stage proposition as regards total output per dollar invested, for any reasonable assumption of rate of power absorption, readily surpassing the latter in 12 years or less, depending upon the rate of absorption. The pressure tunnel is about midway between the two in this respect. Considering the compound two-stage proposition it appears that the pressure tunnel project is a little better, and the power canal project considerably better at a high rate of power absorption, but at a very low rate of absorption the compound two-stage proposition considerably surpasses the pressure tunnel project, and falls very little behind the power canal project.

There is one more consideration worthy of note. In case construction operations on a proposed power development were for any reason suspended before completion, the unproductive expenditure then existing would be smaller for the two-stage than for the single-stage propositions, unless they were very nearly completed.

There is a question as to whether or not the power-development propositions should be required to assume any part of the expense of constructing remedial works just above Horseshoe Falls or elsewhere in Niagara River.

To sum up the comparison of the single-stage and two-stage propositions, there is shown in favor of the single-stage proposition:

1. Lower construction cost per horsepower.
2. Lower unit cost of power production.
3. Greater total financial return per dollar invested, except in case absorption of the power developed takes place at a very slow rate.

There is shown in favor of the two-stage proposition:

1. Increasing advantage as rate of power absorption decreases.
2. Superiority of compound two-stage proposition at very low power-absorption rate.
3. Easier financing.
4. First power produced sooner.
5. Better credit maintained.
6. Total return from sale of power greater for first few years.
7. In case of suspension of construction activities before completion there would be—
 - (a) Smaller capital cost per horsepower produced.
 - (b) Less unproductive expenditure carried.

A study of the foregoing presentation of estimates, facts, and ideas and the comparison and discussion of them leads to the conclusion that for utilizing the present authorized diversion of 20,000 cubic feet of water per second from Niagara River above the falls there is, on the whole very little to choose between the compound two-stage proposition and the power-canal proposition.

The study further shows that for a second development, designed to utilize an additional and similar diversion of 20,000 cubic feet per second, a power-canal project similar to that presented is much cheaper than any other scheme.

The power canal proposed would not be navigable, and it could not properly be made a part of a navigable waterway. No combination of power development with navigable canal from upper to lower river is justifiable on the basis of power production. The La Salle to Lewiston route is the best for a ship canal. It is cheaper to construct this canal of 200-foot width and 30-foot depth for navigation use only, and also the power-canal proposition, than to construct the combined power and ship-canal proposition. The combined proposition would no doubt have more ice difficulties than the power-canal proposition.

In Section E of the report it has been pointed out that 40,000 cubic feet per second may safely be diverted around the Whirlpool and Lower Rapids, this being the total for both sides. The wisdom of diverting any more is doubted, and it is felt that this amount should be diverted first and observation of the resultant effects noted before further diversions are permitted. It was also pointed out that at least 80,000 cubic feet per second might be diverted around the Falls from the Chippawa-Grass Island Pool to the Maid of the Mist Pool, the latter diversion being permissible only on condition that adequate remedial works be constructed just above Horseshoe Falls.

The studies given in the preceding pages indicate that if a new treaty should authorize such a diversion, equally divided between the two countries, the most economical method of utilizing the portions on the American side would be to complete the upper stage of the compound two-stage proposition to care for a diversion of 20,000

cubic feet per second from the Chippawa-Grass Island Pool to the Maid of the Mist Pool, and then, when the market for power was right, construct a single-stage development to care for a diversion of 20,000 cubic feet per second from the Chippawa-Grass Island Pool to the lower gorge at Riverdale Cemetery. The construction of the lower-stage portion of the compound two-stage proposition and the building of another single-stage plant to care for a third 20,000 cubic feet per second remain as interesting possibilities for the future, which might ultimately be built in case observation and study of the effects of increased diversion over a period of years should show these projects to be desirable.

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APPENDIX E.
EFFECTS OF DIVERSIONS UPON LAKE LEVELS.

[Section G of Mr. Richmond's report.]

1. GENERAL PRINCIPLES.

The Great Lakes are essentially a series of natural reservoirs in which are stored large volumes of water collected from their respective drainage basins. The connecting and outflow rivers are the overflows for these reservoirs. The amounts of water in storage are dependent upon the differences between supply and overflow and are measured by the heights of water in the reservoirs. Variations in lake levels thus register the variable differences between net supply and discharge. When the rate of supply to a lake is greater than the discharge, the amount of storage increases and the stage of the lake rises, and when less the storage decreases and the lake falls. Except when obstructed by ice, the outflow or discharge through the natural outlet increases or decreases with the head or stage of water in the lake and with the slope of the outflowing stream. Under these natural laws there is a constant tendency toward equalization of supply and discharge. For instance, if the supply, which is usually variable from month to month and from year to year, should become constant, the stage of water in the lake would soon reach and remain at a height whereby the discharge would exactly equal the supply. If the supply should be increased or decreased by a constant amount, the level of the lake would gradually change until a new level was reached where the supply and discharge would again be equal. There is the same natural tendency toward equalization when through natural or artificial agencies the capacity of the outlet or outlets is changed. Assuming that the stage of a lake is at a height where the supply and discharge are equal, if the outlet is enlarged or an additional outlet is created, the discharge must necessarily be increased for a time, and as the supply is unaffected, the storage is diminished and the stage of water falls. With the falling stage the discharge decreases until the rates of supply and discharge become equal. With a variable supply the effect is fundamentally the same, although it may be masked by the changes in level caused by the change in supply. For instance, if when the outlet is enlarged, the supply happens to increase by a greater amount or faster than the simultaneous increase in capacity of discharge, the result is an increasing stage. However, the increase in stage in such case is less than it would have been without the change in outflow conditions and the lowering effect is real although not apparent.

Such is the effect of uncompensated diversions from the Great Lakes. The water supply to each lake depends on the inflow of

streams; seepage from adjacent ground, rainfall on the lake surface, and evaporation from the lake surface. The supply of the inflowing streams depends primarily on rainfall on and evaporation from their drainage basins. In each drainage basin the run-off and evaporation depend on the nature of the topography, character of the soil, extent and character of the vegetation, and the prevailing winds and temperatures. If the net supply were constant, or if it were precisely measurable, the levels of the lakes could be made to show by direct observation the effects of diversions. Gauge records for this purpose would necessarily extend over considerable periods of time to eliminate effects of wind and atmospheric pressure. Wind effects reach a maximum on Lake Erie, where, during storms, the eastern end is sometimes 15 feet higher than the western end. Because the supply is variable and only roughly determinable, its effects on water levels can not be separated from that of diversions, and hence the latter can be measured or demonstrated only in an indirect way. However, there is a direct relationship between the water levels and the natural capacity for discharge, and, through the determination of this relationship, it is possible to ascertain with certainty the effects on water levels of changes in outflow conditions or of artificial diversions. This may be illustrated by a simple hypothetical case. Consider a small pond or artificial reservoir whose sole supply of water is from a single brook and whose sole outlet is over a fixed weir or dam at the opposite end.

Assuming that the inflow is constant and that there are no losses in the pond, it is obvious that the outflow over the dam will be constant and will equal the supply from the brook; also the depth of water over the crest of the dam, which is measured by the height of water in the pond, will remain constant. This general condition holds true for any constant supply regardless of its amount, but manifestly the depth of water over the dam will not be the same for different rates of supply. If by any means the supply from the brook or its equivalent, the discharge over the dam, is measured, the depth or level of water at the time of measurement will mark the stage which corresponds with the measured rate of supply or discharge. If measurements are repeated for other rates of supply or discharge, and the corresponding heights of water observed, additional equivalents of stage and discharge are determined, and when the number of such measurements is sufficient to plot a graphical curve or derive an empirical equation of relationship between stage and discharge, the discharging capacity of the dam is known for any stage within the limits of observation.

In this suppositious case, consider that the curve or equation of relationship between stage and discharge has been established and that for discharges of 1,000 and 600 cubic feet per second the stages of water are 4 feet and 3 feet, respectively, above the crest of the dam. Suppose a second outlet is created and that when uniform flow has been established it is determined that the flow through the second outlet is 400 cubic feet per second and the stage of water is 3 feet. Manifestly the flow over the dam at the original outlet is 600 cubic feet per second and the supply, which is equal to the total discharge, is 1,000 cubic feet per second. Without the second outlet the

stage would be 4 feet, with it the stage is 3 feet, hence the lowering caused by the second outlet is 1 foot.

Conditions on the Great Lakes are essentially the same as those considered above. The Lakes themselves correspond to the pond, the outflow rivers correspond to the outlet at the dam, and diversions from the Lakes are the same in effect as the discharge through a new outlet. Long series of discharge measurements in the outflow rivers have been made by the United States Lake Survey Office and the results have furnished discharge equations based on stages in the Lakes. By means of these discharge equations the effect upon the levels of the Lakes for any change in outflow conditions may be determined.

Diversions from the Great Lakes may be divided into three classes in respect to their effect upon water levels, namely, (a) those which are returned to the same body or level of water from which they are diverted, and which consequently have no permanent effect upon the water levels, (b) those which are returned to a lower level of water in the Great Lakes basin and which, unless compensated for, lower the levels of those bodies of water at and somewhat upstream from the point of withdrawal and all the others downstream from them to but not beyond the body of water to which they are returned, and (c) those which are permanently removed from the basin and which lower water levels at and, in some cases, upstream from the point of withdrawal and all those downstream through the lower lakes and rivers to the level of the sea. The upper limits of effects produced by the latter two classes of diversions are the uppermost levels of water which are dependent upon or are effected by the levels at the points of withdrawal.

Examples of the three classes of diversions and the limits of their effects on water levels are as follows:

(a) Water pumped from Lake Michigan at Milwaukee for the flushing of Milwaukee River, or water pumped for sanitary purposes at Duluth, Toledo, Cleveland, and other cities similarly situated, is returned directly to the Lakes, and obviously does not change the net supply to these Lakes or the volume of outflow through their natural outlets, and hence does not affect their levels.

(b) Diversions from Lake Erie, through the Welland Canal lower the waters of the lakes and rivers from the head of Lake Michigan and the foot of St. Marys Falls down to the lower end of Niagara River. As the water is returned to Lake Ontario they do not affect the levels of that lake nor of the St. Lawrence River.

(c) The diversion from Lake Michigan through the Chicago Drainage Canal lowers all lakes and rivers of the Great Lakes system down to the Gulf of St. Lawrence with the exception of Lake Superior and St. Marys River above the foot of St. Marys Falls.

2. OUTLETS OF THE LAKES AND FORMULAS OF DISCHARGE.

St. Marys River.—The natural outflow from Lake Superior is through the St. Marys River, and the level of the lake was originally determined by the natural discharging capacity of St. Marys Falls. These rapids, with a fall of about 19 feet in less than a mile, form practically a free overfall weir; in other words, changes in the level of the water at their foot have no effect upon their discharging capacity.

The natural flow has been changed by the construction of the piers of the international railroad bridge, by filling in along either shore, by the construction of canals and locks on both sides of the river, by the diversion of water for power purposes, and by the construction of regulating works in the river above the international bridge.

Measurements of the flow of the river have been made by the Lake Survey Office in 1896, 1899, 1900, 1901, 1905, and 1908, each series of measurements determining the relation between stage and flow for the particular time in which they were made. Since the time of the last measurements the restrictions have been increased, until at the present time there is only about 25 per cent of the original area and 33 per cent of the original discharging capacity open to free flow. Twenty-two per cent of the area and 11 per cent of the discharge is obstructed by the head race of the United States Power Station, formerly owned and operated by the Chandler-Dunbar Water Power Co., and by the permanent structures of the controlling works, while 53 per cent of the area and 56 per cent of the original capacity of discharge are under direct control by means of the movable gates of the regulating works. Present plans contemplate further extension of controlling works to the full width of the open river, and a portion of these works are under construction. It is probable that the outflow from Lake Superior will be brought under full control at some not far distant date.

St. Clair River.—The natural outlet from Lakes Michigan-Huron is through the St. Clair River, which is relatively broad and deep with but little fall. The flow through the river depends, therefore, not only upon the elevation of Lake Huron, but also upon the elevation of Lake St. Clair, which in turn depends upon the elevation of Lake Erie. Measurements of the flow of the St. Clair River have been made by the United States Lake Survey during two periods, each covering several seasons, the first 1899-1902, the second 1908-1910. As there was no material change in the regimen of the river between these periods, all of the measurements were available for the determination of a law of discharge. As the stage of Lake St. Clair usually follows that of Lake Huron rather closely, the differentiation of headwater and backwater effects is somewhat difficult. Using a modified formula for a submerged weir, an equation has been derived by the Lake Survey Office which fits the observations excellently and appears to be satisfactory. This equation, which applies to present conditions and is good at least as far back as 1903 and possibly 1895, is as follows:

Discharge cubic feet per second St. Clair River = $3758 ((H-567.51) + 1.25(h-567.51))(H-h)^{\frac{3}{2}}$

in which H is the elevation above sea level on the Fort Gratiot gauge and h is the elevation above sea level on the St. Clair Flats Canal gauge.

As the elevation of Lake Huron is usually determined by or referred to readings of the Harbor Beach gauge, the formula has been modified to fit elevations at Harbor Beach by means of a known law of relationship. The modified formula is:

Discharge cubic feet per second St. Clair River = $3820 ((H'-567.50) + 1.135(h-567.50))(H'-h)^{\frac{3}{2}}$

in which H' is the elevation above sea level on Harbor Beach gauge and h is the elevation at St. Clair Flats.

Detroit River.—The Detroit River may be considered a continuation of the St. Clair River, and hence a section of the discharge channel from Lake Huron, Lake St. Clair being merely an expansion of this channel with comparatively small storage capacity. Some measurements of the flow in the Detroit River were made by the Lake Survey in 1901–1902, but they are too few in number and do not cover a sufficient range in stages to establish a law of flow.

As the local supply to Lake St. Clair is small and fairly uniform during the summer months, it is possible to determine an approximate discharge formula for the Detroit River from the equation for the St. Clair River. From the monthly mean water levels at Harbor Beach and St. Clair Flats, June to November, inclusive, for the years 1912–1918, inclusive, during which period there is no evidence of change in the regimen of either river, the discharge of the St. Clair River for each month has been computed; and with these values of the discharge and the corresponding observed elevations at St. Clair Flats and Cleveland, an equation has been derived in terms of these latter gauges. This equation is:

$$\text{Discharge cubic feet per second Detroit River} = 10767 ((h - 567.25) + 0.44(h' - 567.25)) (h - h')^{\frac{1}{2}}$$

in which h is the elevation above sea level at St. Clair Flats Canal gauge and h' the elevation above sea level on the Cleveland gauge.

The values given by this equation do not include the local supply to Lake St. Clair and St. Clair River, owing to the manner of its derivation.

Changes in regimen in the St. Clair and Detroit Rivers.—It appears probable that there have been some changes in the regimen of the St. Clair and the Detroit Rivers since the first gauge records on these rivers were obtained. In the case of the St. Clair River these have probably not been large, and there have been no changes of moment due to improvements for navigation purposes since the construction of the canal at St. Clair Flats. Small changes in the regimen apparently occur from year to year due largely to movement of the material which overlies the true bottom. During storms some material, principally sand and gravel, is brought into the river from the shores of Lake Huron, and is carried from point to point down the river by varying velocity and direction of the current. Bars are built up along the shores in the rapids at the head of the river in the fall, but are of short duration. Dredging on Black River Shoal and in the river above it appears to have but little effect on the depth, the material excavated being replaced within a short time. There is evidence in the measurements of the flow indicating that these small changes occur from year to year, but are only temporary. The measurements of flow made in 1902 compared with those made in 1901 show a change in discharge capacity of about 8 per cent, while the measurements of 1909 and 1910 are about midway between those of 1901 and 1902. In 1898–99 four sections were established near the head of the river, and were very carefully sounded. Soundings made since on these sections indicate that there has been no measurable change in the cross-section of the river.

In the Detroit River there has probably been less change in discharging capacity due to natural causes than in the St. Clair River, but the changes due to improvements for navigation and other purposes have undoubtedly been larger. The construction in 1872 of the

bridge at Trenton west of Grosse Isle and the pier extending some 1,300 feet into the main channel from Stony Island materially decreased the cross-section of the river, and the encroaching dock line along the Detroit river front and some large fills on the Canadian side have further lessened the discharging capacity. The construction of the Belle Isle bridge in 1889 obstructed an appreciable part of the cross-section of the channel west of Belle Isle, and must have had some effect on the discharging capacity of the river. On the other hand, dredging at Lime Kiln Crossing and at other points has tended to increase the capacity of the river. Thus the Detroit River has undergone a number of minor changes in regimen, the effect of which has been compensating to a considerable extent.

The greatest change in regimen and the only one of which the effects were directly observed was that occurring in the years 1908-1911, when the cofferdam around the upper section of the Livingstone Channel was in place. This cofferdam, by decreasing the cross-section of the river, east of Grosse Isle, caused an appreciable back water in the upper Detroit River and Lake St. Clair. The rise at St. Clair Flats was observed to be 0.28 foot. When this cofferdam was cut, in 1912, Lake St. Clair dropped back to its natural level, thus showing that the remaining portions of the cofferdam, together with the judicious placing of spoil, had exactly balanced the effect of the new channel.

That there has been any large change in the discharging capacity of the St. Clair-Detroit River appears improbable. The elevation of the surface of Lake St. Clair, lying between Lakes Huron and Erie, depends almost entirely upon the elevations of these two larger lakes. Any change in the regimen of either river will cause a change in the relative elevation of Lake St. Clair. This is illustrated nearly every winter at times when one or the other of the rivers is blocked with ice. The elevation of the surface of Lake St. Clair therefore becomes an index of any change in the regimen of either river.

By means of the equations of discharge of the two rivers the normal elevations of Lake St. Clair may be computed for any particular stages of Lakes Huron and Erie. On Plate No. 52 is shown the difference between the observed and the computed elevations of Lake St. Clair in periods of three years, each year consisting of the six summer months, June to November, inclusive. This plate shows a rise in Lake St. Clair from 1872 to 1881 of about 0.2 foot which might be caused by an increased flow in the St. Clair River or a decreased flow in the Detroit River of about 12,000 cubic feet per second, or 6 per cent in the discharge. From 1883 to 1889 there appears to be a lowering of about 0.25 foot in Lake St. Clair which corresponds with an opposite change of about 15,000 cubic feet per second, or 7 per cent in the discharge. From 1889 to 1895 the level of Lake St. Clair shows a rise of about 0.15 foot corresponding to a change of 9,000 cubic feet per second, or 4 per cent in the discharge. Since 1895 there appears to have been no change except those due to the construction of the cofferdam at the Livingstone Cut in 1908 and its opening in 1912.

Whether or not these are real changes is doubtful. But little is known of the accuracy of the gauge at St. Clair Flats in the earlier years. The first levels were run to this gauge in 1903, and the elevation of its zero determined at that time has been used for all the

earlier readings. Precise levels run in 1903 and again in 1917 show a settlement during this period of about 0.4 foot. It seems quite probable therefore that there was some settlement prior to 1903. The rise in the observed elevations of Lake St. Clair from 1887 to 1895 shown on the plate may easily be due to such settlement. The changes prior to 1887 are not easily explained. From 1872 to 1883 a rise is shown equal in magnitude to that caused by the cofferdams at the Livingstone Cut, and extending over a longer period, while from 1883 to 1889 there is a drop greater than this rise. There is no record of artificial changes in either river that will account for such changes in Lake St. Clair levels and it appears improbable that natural causes could produce such effects. The natural conclusion is that the records of Lake St. Clair levels prior to 1903 are of little value in determining changes in regimen in the channel between Lakes Huron and Erie.

The comparative elevations of Lakes Huron and Erie offer no better evidence. While the net local supply of Lake Erie is only about 10 per cent of its total supply, the percentage variation in the former is much greater than the percentage variation in the flow from Lake Huron, and hence the changes in elevation of Lake Erie are not closely dependent upon the fluctuations of Lake Huron. This is particularly true on account of the comparatively small storage capacity of Lake Erie where a change of 10 per cent in the local supply during a year will change its stage about 3 inches.

By grouping several years, for the purpose of reducing this variation in net supply, and comparing the mean stages of Lake Erie with the elevations of Lake Huron for corresponding periods, there is found to be a somewhat close relationship between the two. Plate No. 53 shows the mean elevations of Lake Erie (June to November, inclusive) in chronological periods of four years from 1860 to 1918, plotted against the elevations of Lake Huron for the same periods. If, by such grouping, the variation in local supply were eliminated, and the ice effects, which will be discussed later, were to average the same for all groups, then these points would either fall in one line on the plot or by deviating therefrom would indicate positively and accurately the effects of changes in regimen of the channel between the two lakes. Because the variations in net local supply and in ice effects can not be eliminated in grouping the observations the points scatter and the indications are not conclusive. It will be noted that there is a slight tendency for the levels prior to 1889 and those subsequent to that date to fall on lines parallel to each other, with Lake Huron about three-tenths foot lower during the latter period for the same elevation of Lake Erie. This is not well established, however, as the stages during the two periods do not overlap, and a single line through all observations fits almost as well. Whether or not there has been any marked change in the level of Lake Huron due to change in regimen of its outflow channel is still a mooted question and probably will remain so unless the stages of the lakes should return to the high levels of the eighties. It is reasonably certain, however, that there has been no great amount of change in the discharging capacity of the St. Clair and Detroit Rivers.

Niagara River.—The natural outlet from Lake Erie is through the Niagara River. The outflow is controlled by the section of river about 19 miles long with a fall of some 10 feet between Lake Erie

and the first cascade above Niagara Falls. The outflow is usually considered as that over a free overfall weir, depending entirely upon the elevation of Lake Erie, but this is not strictly true. A more accurate conception is that of flow over a submerged weir with its headwater in Lake Erie and its tail-water the river from the vicinity of Austin Street to the first cascade. As the upper portion of the river lies through limestone rock, natural changes in regimen must be very slow, and are inappreciable since the establishment of gauges on the lakes. Measurements of the flow have been made at three sections in the years 1899, 1900, 1907, 1908, and 1913. The accepted equation for the flow of the river is—

Discharge cubic feet per second, Niagara River = $3904(H-558.37)^{3/2}$

in which H is the elevation above sea level on the Buffalo gauge.

This formula is not quite accurate during rapidly changing stages, as the flow is affected by the elevation of the water surface in the river below Austin Street and owing to the storage capacity in the Niagara River above the Falls the stage at Austin Street does not respond instantly to changes in elevation of Lake Erie at Buffalo. For a change in the elevation of the water surface of 0.10 foot at Austin Street with respect to Lake Erie stages, the discharge is affected by approximately three-fourths of 1 per cent.

St. Lawrence River.—The natural outflow from Lake Ontario is through the St. Lawrence River. The first 63 miles of this river from Lake Ontario to Ogdensburg is broad and deep, with but little fall, and may be regarded as an arm of the lake. A short distance below Ogdensburg are the Galop Rapids, the first of the series of rapids by means of which the water falls 240 feet to sea level. The Galop Rapids, with a fall of some 16 feet, form the weir controlling the outflow from Lake Ontario. This weir is considered of the free overfall type, inasmuch as changes in the elevation of the water surface below have no appreciable effect upon its discharging capacity.

The discharging capacity of the St. Lawrence River has changed from time to time, due to improvements for navigation. Previous to 1883 the records of gauge heights on the river are not sufficiently complete to determine the relationship between the slope and the discharge with any degree of certainty. In 1884 the deepening of the canals and the reconstruction of the locks began and for several years conditions were in a transitory state. By 1888 a condition of relative stability was reached, and conditions remained practically constant until 1897. In 1897 work was begun on the North Cut at the head of the Galop Rapids, where a cofferdam was built and the channel was excavated in the dry. Late in 1899 the cofferdam was cut, and in May, 1900, the North Cut was opened to navigation. In September and October, 1903, the channel between Adams and Galop Islands, known as the Gut, was closed by a dam which materially reduced the flow of the river. Since 1904 there have been no known changes affecting the outflow from Lake Ontario.

Measurements of discharge have been made by the Lake Survey Office in six separate seasons, namely, 1900, 1901, 1908, 1911, 1913, and 1914. The first two were before the construction of the Gut Dam and the last four subsequent thereto. By means of the measurements

and the records of gauges on the river discharge equations have been determined in the Lake Survey Office representing the relationship between the volume of flow and Lake Ontario stages subsequent to 1887. This period has been divided into four epochs, the first, 1888-1897, being the condition following the completion of St. Lawrence Canals and prior to the work on the North Cut; the second, 1899-1900, being the condition while the cofferdam was in place around the North Cut; the third, 1900-1902, being the condition just prior to the construction of the Gut Dam; and the fourth, 1904 to date, being the present condition. The equations of discharge of the St. Lawrence River for the four epochs are as follows:

1888-1897, discharge cubic feet per second = $3729 (H-229.53)^{3/2}$

1898-1899, discharge cubic feet per second = $3650 (H-229.44)^{3/2}$

1900-1902, discharge cubic feet per second = $3728 (H-229.50)^{3/2}$

1904-1918, discharge cubic feet per second = $3428 (H-229.13)^{3/2}$

in which H is the elevation above sea level on the Oswego gauge.

3. EFFECT OF ICE ON RIVER FLOW AND LAKE LEVELS.

The equations for determining the flow through the various connecting rivers of the Great Lakes system apply only during open-season conditions. During the winter months, when there is more or less ice in the rivers, the flow is retarded, at times as much as 50 per cent of the normal flow, and during these periods the equations do not give the discharge. There are methods, however, by which an approximation to the flow during ice periods may be made.

St. Marys River ice effects.—The retardation of flow in the St. Marys River is due to the ice cover on the river from Lake Superior to the head of the rapids, ice jams in the rapids occurring infrequently, if at all. It can be shown that during the winter months the elevation of the gauge at the head of the rapids (southwestern pier) averages about 0.13 foot lower than it does in the summer for the same stage of Lake Superior. This corresponds to a retardation in the flow of the river of about 2,800 cubic feet per second for these three months. The effect on the level of Lake Superior is very small, amounting at most to a few hundredths of a foot.

St. Clair-Detroit River ice effects.—The St. Clair and the Detroit Rivers are normally covered with ice during the winter months, except in the vicinity of Port Huron and of Detroit, where the ice is broken up by ferry boats. In addition to the normal ice cover, jams or blockades are of frequent occurrence, and at times hold back large quantities of water. Blockades usually form in the Detroit River in late December or early January, followed in February and March by ice jams in the St. Clair River. These latter continue into April and occasionally into May. It has been reported that in 1819 and in 1840 the St. Clair River was blocked with ice in June. After the breaking of the blockade in the St. Clair River each year there is frequently a blockade of short duration in the Detroit River.

If both the St. Clair and the Detroit Rivers were never blocked with ice at the same time, the actual flow through the rivers could be computed by means of the equation for that river which was free of ice. It appears probable, however, that this condition rarely exists, although it is unusual for large blockades to appear in both rivers at the same time.

During the winter of 1900-01 measurements of the flow in the St. Clair River were made while the river was blocked with ice. From these observations combined with those made under ice-free conditions, the flow of the river has been referred to the stage at the Grand Trunk Railway gauge (G. T. R.) and to the fall from that gauge to the gauge at the mouth of Black River (M. B. R.). The flow is expressed by the empirical formula:

$$\text{Discharge cubic feet per second} = (\text{G. T. R.} - \text{M. B. R.})^{0.4} \\ (239750 + 20320 (\text{G. T. R.} - 579.0)).$$

This equation may be used for computing the flow of the river during the winters from 1900 to 1906, inclusive, during which the mouth of Black River gauge was maintained. If there is no ice in the river between the Grand Trunk Railroad gauge and the Dry Dock gauge, the elevations at mouth of Black River may be computed from G. T. R. and Dry Dock. The Dry Dock gauge was maintained until the summer of 1909, when it was discontinued.

For the years 1900-1902, during which period there can be no question of the accuracy of the Grand Trunk Railroad and the Mouth of Black River gauges, the average retardation of flow for six months, computed from these gauges was 24,500 cubic feet per second. For the same period a comparison of the computed discharges of the St. Clair and Detroit Rivers shows a retardation of 17,600 cubic feet per second or 28 per cent too small. This difference is undoubtedly due to the presence of ice in both rivers at the same time and shows that a comparison of the computed discharges of the two rivers can not be relied upon for the determination of the full effect of ice.

In the Detroit River the reach from Windmill Point to Fort Wayne is usually free from ice blockades, although there is normally an ice cover over portions of the reach. An empirical formula giving the flow of the Detroit River in terms of the gauges at Windmill Point and Fort Wayne has been derived, and may be used to approximate the winter flow. This equation is as follows:

$$\text{Discharge cubic feet per second} = (\text{W. P.} - \text{Ft. W.})^{\frac{1}{3}} \\ (192,900 + 25,850 (\text{W. P.} - 574.0)).$$

Using this equation for the period 1906-1918, the mean six months' retardation of flow is 17,600 cubic feet per second. The corresponding mean determined by a comparison of St. Clair and Detroit River discharges is 13,900. In this case the latter method gives results 21 per cent less than the former.

The average yearly retardation due to ice in cubic feet per second, as computed in various methods, is shown below:

(a) By Grand Trunk Railroad and Mouth of Black River gauges, 1900-1904	12,200
(b) By Grand Trunk Railroad and Mouth of Black River gauges, 1900-1909	9,980
(c) By Windmill Point and Fort Wayne gauges, 1906-1918	8,810
(d) From best data for each year, 1900-1918	9,790
Mean	10,200

It may therefore be assumed that the average yearly retardation due to ice in the St. Clair and Detroit Rivers amounts to about 10,000 cubic feet per second for 12 months.

The maximum retardation of flow in this period occurred in April, 1918, and amounted to 92,400 cubic feet per second for the month. For the 5 days, April 22-26, inclusive, the retardation was 115,300 cubic feet per second, which was 54 per cent of the normal flow for the stages existing in Lakes Huron and Erie.

The determination of ice effects as described above shows that the average retardation of flow in the St. Clair-Detroit Rivers of 10,000 cubic feet per second for the year is distributed as follows:

	Cubic feet per second.
December	6,200
January	27,500
February	42,500
March	28,000
April	14,300
May	1,500
Total	120,000

(An average of 10,000 cubic feet per second per annum.)

Ice in the St. Clair-Detroit River, by reducing the outflow from Lake Huron, raises the level of Lake Huron, and lowers the level of Lake Erie. When the ice goes out, Lake Huron has a supernormal elevation, and Lake Erie a subnormal elevation. The increased elevation of Lake Huron and the increased fall in the river causes an increased flow, tending to restore both lakes to the normal elevation.

On account of the great area of Lake Michigan-Huron it takes a long time for the lake to lose the excess elevation caused by the ice. Ninety per cent will be lost in about four years. In 10 months about 32 per cent is lost. It is apparent, therefore, that Lake Huron is always at a higher stage, due to the annual ice blockades, than it would be if there were never any ice in the rivers.

Lake Erie, on the other hand, has a relatively small area, and recovers its normal elevation much more quickly than does Lake Michigan-Huron. In 10 months about 93 per cent of the depression caused by ice is recovered.

On plates Nos. 54 and 56, curves A show for Lakes Michigan-Huron, and for Lake Erie the mean annual change in elevation computed from the monthly means of 50 years, 1860 to 1909. These curves correspond to a mean open season outflow from Lake Huron of 198,500 cubic feet per second, and to mean outflow from Lake Erie of 198,500 cubic feet per second plus 11,000 cubic feet per second, the mean annual local supply, or a total of 209,500 cubic feet per second.

If, through a sudden change of climate, the formation of ice in the connecting rivers should be stopped, the resulting annual curve for the first year is shown on plates Nos. 54 and 56, marked "C." This curve is based on the same mean local supply to both lakes, but owing to the excess elevation of Lake Huron, the mean flow out of Lake Huron and into Lake Erie is 204,000 cubic feet per second, while the mean outflow from Lake Erie is 215,000 cubic feet per second. If the ice-free condition continues indefinitely with the same average net supply the lake levels will reach a new point of equilibrium at which the outflow from each lake will be the same as for curves A. The annual fluctuation for this condition is shown by

the curves marked "B." The mean yearly elevation of Lake Huron will be 0.48 foot less than it was under the ice condition, and the stage for every month will be less. Lake Erie will stand at the same mean elevation, but will be higher during February, March, April, May, and June, and lower during the other months than it was with ice in the St. Clair-Detroit River.

On plate No. 55 is shown the fall between Lake Huron and Lake Erie as it exists under the present conditions, and as it would be under the conditions explained above. It will be seen that the fall between the two lakes in one year without ice approaches very closely to what it would ultimately become under a perpetual ice-free condition.

Niagara River ice effects.—With the data available at the present time, it is impossible to determine the retardation of flow through the outlet of Lake Erie, due to the presence of ice in the Niagara River. A few measurements of river flow made by the Deep Waterways Commission in 1898 indicate that at times the retardation may reach 10 per cent, although it is usually much less. There is at times some ice lodged against the piers of the International Bridge and against the waterworks intake. The partial ice cover on the river between the bridge and Niagara Falls, together with ice jams in the vicinity of the Falls, undoubtedly cause some backwater. If an average retardation of 3 per cent of the normal flow for three months is assumed, the maximum effect on the surface of Lake Erie would amount to about 0.18 foot in depth, and the effect on the yearly mean stage would be about 0.07 foot.

St. Lawrence River ice effects.—The effect of ice on the flow of the St. Lawrence River may be approximated very closely from records of the numerous gauges along the river. This river may be considered as a series of pools between which the rapids form measuring weirs. The three upper rapids have been calibrated. The initial weir, which controls the outflow from Lake Ontario, is formed by the Galop Rapids. Discharge over this weir may be computed by means of any gauge on Lake Ontario, by the gauge at Ogdensburg, or by the gauge at Lock 27 of the Canadian Canals. As there is normally an ice cover from Lake Ontario to the head of the rapids, the gauge at Lock 27 is the most accurate measure of the discharge over this weir during the winter months. The flow over the second weir, Rapide Plat, is measured by the stage of water at Lock 24. For the third weir, the Sault Rapids, there are four gauges available. Immediately at the head of the Rapids is the gauge at Lock 21. At Lock 22 of the Farrans Point Canal there are two gauges, and at the foot of Rapide Plat is the gauge at Lock 23. The equation of discharge has been written in terms of the latter gauge, as the others appear to have been affected at one time or another either by settlement or by changes in the local conditions. While there undoubtedly is more or less ice between the gauge at Lock 23 and the head of the Sault Rapids, yet an attempt to use any of the other gauges would introduce errors greater than the retardation due to ice.

If any of the three weirs is blocked by ice, its discharging capacity for a given gauge height is reduced, and the flow computed from the observed elevation on the gauge will be too large. It is not likely that all three rapids will be blocked at the same time, and the equation

giving the least flow approximates the actual discharge. This minimum flow subtracted from the flow as computed by the Oswego gauge gives the amount of water held back by the ice. This method tends to give results somewhat too small, as there probably is some retardation at all of the rapids simultaneously. The mean retardation of flow due to ice, computed in the manner explained above, for 29 years, 1888 to 1916, is as follows:

	Cubic feet per second.
December	3,600
January	9,900
February	19,100
March	13,800
April	6,400
Total	52,800

(An average of 4,400 cubic feet per second per annum.)

If the outflow from Lake Ontario is reduced while the total supply to the lake remains the same, the elevation of the lake surface will rise and will continue to rise as long as the outflow is retarded by ice. When the ice goes out, the lake has an excess elevation. As the outflow is above normal the lake begins to lose its excess height. On account of the small area of Lake Ontario and the large outflow, the time necessary to lose this excess height is relatively short, and at the end of 10 months about 98 per cent will have been lost.

On plate No. 57 curve A shows the mean annual fluctuation of the surface of Lake Ontario for 50 years. This curve corresponds to an outflow through the St. Lawrence River of 237,600 cubic feet per second.

If ice should cease to form in the St. Lawrence River, the outflow during the winter would be increased and the mean lake surface would fall, until a stage was reached at which the outflow during the year would again equal the total supply. When this condition is reached, the mean average fluctuations of the lake would be as shown by curve B on plate No. 57. This curve averages 0.21 foot below curve A, this difference being the average amount the surface of the lake is held up by the presence of ice. The fluctuation during the first ice-free year is shown by curve C. It will be noted that this curve joins curve B and coincides with it during the last three months of the year. This indicates that the storage of water in Lake Ontario on account of winter ice in the St. Lawrence River is practically all discharged during one ice-free year.

4. HYDROLOGICAL DATA.

During recent years the Lake Survey Office has compiled the records of rainfall in the Great Lakes Basin as reported by the voluntary cooperative observers of the weather bureaus of the United States and Canada, and by means of a system of weighting the observations has determined the mean monthly rainfall since 1900 for the drainage area of each of the Great Lakes. There has also been determined the mean monthly rainfall over the lakes themselves, in contrast to that over the land areas, by weighting observations taken at points along the shores. This appears to be the best method of arriving at values for such rainfall, inasmuch as there

have been no direct observations over the water areas. On all of the lakes, with the exception of Lake Ontario, the differences between rainfall on the lake surface as thus determined and that on the land areas are small and appear to be accidental. In the case of Lake Ontario there is a marked difference, the annual precipitation along the lake shores averaging nearly 2 inches less than in the interior.

Compilations have also been made of the flow of streams tributary to the Great Lakes, as measured and reported by the United States Geological Survey and the Hydroelectric Power Commission of Ontario, Canada, utilizing all the available data. The distribution of these records over the drainage areas is not what could be desired, there being large areas in which no measurements have been made. This data is also subject to errors due to methods of measurement, instability of gauges, etc., and it is suspected from a study of the records themselves that corrections have been made to the discharge formulas from time to time without applying the corrections to values previously published, and that for some periods the discharge of certain streams as published has included the flow through by-passes or side streams, while in other years these have been omitted.

From these data of rainfall and run-off an attempt has been made to show, as far as possible, the source of the water passing down through the Great Lakes and to show the correlation of the discharge measurements on the various connecting rivers by means of the meteorological data. The results of this analysis are embodied in Table No. 45, which has been compiled for a 10-year period, 1905-1914, inclusive. In this table the quantities are not all of equal accuracy. The areas of the lake surfaces and the drainage areas are the results of very careful measurements from the best available charts. They are probably accurate within a small percentage. The rainfall in columns g and h are weighted means derived from observations at several hundred stations, and probably are not largely in error. The rainfall on the lake surfaces has been taken the same as the averages for the corresponding land areas, with the exception of that on the surface of Lake Ontario. For this lake the observations at the shore stations indicate a mean annual rainfall of 31.75 inches, which is nearly 2 inches less than the mean of observations in the adjoining drainage areas. This value of 31.75 inches rainfall has been used for the water area of Lake Ontario. The run-off from the land areas has been expressed and computed as percentages of the corresponding rainfall. There is, of course, no fixed percentage relationship between rainfall and run-off, but the values here given are averages derived from weighted means of all observations within the respective basins during the period covered, and give practically the same results as would be obtained from the data through any more complicated method of deduction.

The amount of water flowing out of any lake must, of necessity, be the algebraic sum of the water entering the lake from the lake above, the local gross supply, the storage in the lake, and the water lost by evaporation. All of these factors are known with some degree of certainty, except the evaporation from the lake surface. Accepting the other factors as correct, this one may be computed, and from the reasonableness of these computed values the accuracy of the other factors may be judged.

The outflow from Lake Superior has been taken from records kept by the United States Engineer office at Sault St. Marie. The flow through the St. Clair River is computed by means of the Lake Survey equation for open-river conditions, and the result corrected by subtracting 10,000 cubic feet per second to allow for the retardation of flow during the winter months. The outflow through the Sanitary Canal at Chicago is taken as 5,850 cubic feet per second, which corresponds to the mean diversion during the period.

The outflow from Lake Erie is the flow through the Niagara River, computed by the Lake Survey equation, corrected by subtracting 1,500 cubic feet per second for the retardation due to ice in winter, and by adding 3,500 cubic feet per second, the estimated flow through the Welland Canal and other outlets. The outflow from Lake Ontario is the discharge through the St. Lawrence River, computed by the Lake Survey equation for open flow, corrected by subtracting 4,400 cubic feet per second for the retardation due to ice.

The values for the evaporation, which are derived as residuals from the other factors, are found to be reasonably harmonious and to agree fairly well with the very meager data of evaporation in the lakes district. These values show beyond doubt that the discharges in the outflow channels of the Great Lakes as determined by the adopted discharge formulas are consistent with each other, and that there is no ground for the theory advanced by some engineers that there is a large subterranean flow from Lake Erie to Lake Ontario.

TABLE No. 45.—*Water supply of the Great Lakes—Average annual values for the 10-year period 1905-1914, inclusive.*

	Area of water surface (square miles).			Total area of drainage basin (square miles).			Average rainfall (inches).		Average run-off (per cent).		Gross supply from rainfall on lake (cubic feet per second).		
	Canada.		Total.	Canada.		Total.	U. S.	Canada.	U. S.	Canada.	U. S.	Canada.	Total.
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(k)	(l)	(m)	(n)
Lake Superior.....	20,710	11,100	31,810	37,420	43,280	80,700	27.53	27.99	46	50	42,000	22,640	64,640
Lake Michigan.....	22,400	13,900	36,300	69,040	47,610	116,650	31.68	31.55	35	60	52,280	15,180	67,460
Lake Huron.....	9,110	7,000	16,110	24,900	11,610	36,510	28.83	28.86	43	60	19,350	16,270	35,620
Lake Huron, excluding Georgian Bay and North Channel.....		6,900	6,900	25,880	36,000	41,900	35.58	33.11	27	36	13,550	12,760	26,310
Georgian Bay and North Channel.....	5,170	5,230	10,400	18,720	15,920	34,640	35.60	31.10	48	53	8,330	9,310	17,640
Lake St. Clair-Erie.....	3,560	3,960	7,520	15,730	10,610	26,340	.....	.....	.....	.....	127,180	66,850	194,030
Lake Ontario.....	3,560	3,960	7,520	15,730	10,610	26,340	.....	.....	.....	.....	74,900	66,850	141,750
Totals above Niagara Falls:	57,390	30,220	87,610	157,330	106,110	263,440	.....	.....	.....	.....	74,900	66,850	141,750
Excluding Lake Michigan.....	34,990	30,220	65,210	88,290	106,110	194,400	.....	.....	.....	.....	74,900	66,850	141,750
Excluding Lake Michigan, Georgian Bay, and North Channel.....	34,990	23,330	58,320	88,290	70,110	158,400	.....	.....	.....	.....	74,900	51,670	126,570
Totals above Galop Rapids:	60,950	34,210	95,160	176,050	122,030	298,080	.....	.....	.....	.....	135,510	76,160	211,670
Excluding Lake Michigan.....	38,550	34,210	72,760	107,010	122,030	229,040	.....	.....	.....	.....	83,230	76,160	159,390
Excluding Lake Michigan, Georgian Bay, and North Channel.....	38,550	27,310	65,860	107,010	86,030	193,040	.....	.....	.....	.....	83,230	60,980	144,210

TABLE No. 45.—*Water supply of the Great Lakes—Average annual values for the 10-year period 1905-1914, inclusive—Continued.*

	Gross supply from run-off from land (cubic feet per second.)			Total gross supply (cubic feet per second.)			Mean annual evaporation (inches).	Total net supply (cubic feet per second).			Storage (cubic feet per second).	Outflow (cubic feet per second).
	Canada.		Total.	U. S.		Total.		U. S.		Total.		
	(o)	(p)	(q)	(r)	(s)	(t)		(u)	(v)	(w)	(x)	(y)	(z)
Lake Superior.....	15,590	32,820	48,410	57,590	55,460	113,050	18.67	29,110	40,190	69,300	-1,800	71,100
Lake Michigan.....	38,100		38,100	90,880		90,880	26.08	47,350		47,350	-1,230	
Lake Huron.....	14,500	44,830	59,330	33,850	76,280	110,130	26.08	16,350	49,370	65,720	-1,280	196,880
Lake Huron, excluding Georgian Bay and North Channel.....	14,500	6,430	20,930	33,850	22,700	56,550	26.08	16,350	9,250	25,600		
Georgian Bay and North Channel.....		38,400	38,400		53,580	53,580	26.08		40,320	40,320		
Lake St. Clair-Erie.....	14,660	8,770	23,430	28,210	21,530	49,740	34.97	14,890	8,060	22,950	-350	204,300
Lake Ontario.....	19,100	14,500	33,600	27,430	23,810	51,240	33.14	18,740	14,060	32,800	-	227,800
Totals above Niagara Falls:												
Total.....	82,850	86,420	169,270	210,090	153,270	363,360		107,700	97,820	205,520		
Excluding Lake Michigan.....	44,750	86,420	131,170	119,650	153,270	272,920		60,350	97,820	158,170		
Excluding Lake Michigan, Georgian Bay, and North Channel.....	44,750	48,020	92,770	119,650	99,090	219,340		60,350	57,500	117,850		
Totals above Galop Rapids:												
Total.....	101,950	100,920	202,870	227,460	177,080	414,540		128,440	111,910	238,350		
Excluding Lake Michigan.....	63,850	100,920	164,770	147,080	177,080	324,160		79,090	111,910	191,000		
Excluding Lake Michigan, Georgian Bay, and North Channel.....	63,850	62,520	126,370	147,080	123,500	270,580		79,090	71,590	150,680		

5. EFFECTS OF PRESENT DIVERSIONS.

The ultimate effect of diversions upon the level of a lake or body from which they are drawn is a direct function of the amount or rate of the diversions and the increment of discharge through the main outlet. When these values are known with some degree of accuracy the lowering effect of the diversions can be determined with equal accuracy. For the outlets of the Great Lakes, the equations of discharge have been determined for open-season flow by long series of measurements in the outflow channels, and the increments of flow for such conditions are well established. The effects of winter ice upon the average flow through the outflow channels can be roughly approximated from direct measurements which have been made or from a study of gauge relations and slopes as has been shown in a preceding article, but the effects of ice upon the increments of flow is not determinable from existing data. In the discussion of ice effects an average retardation of ice has been applied to the open-season discharge values without regard to the stage of water in the lakes or the amounts of discharge. In effect this method considers that the increments of open-season flow continue through the ice season. In the following discussion of the effects upon water levels of diversions from the lakes and rivers, the increments of discharge determined by the equations of open-season flow have also been used without correction for winter conditions for the reason that the amounts of such corrections are indeterminate. It is reasonable to believe that the increments are smaller in the winter than in the summer and that therefore the effects of diversions are actually larger than herein shown.

Diversions from Lake Superior.—With the exception of temporary withdrawals of water from Lake Superior for water supply of the cities around the lake, all present diversions from this lake are made in the immediate vicinity of Sault Ste. Marie, Mich., and Ontario. These diversions have been fully described previously in this report, those pertaining to the navigation canals in Section A and those pertaining to power development in Section C. The present diversions are estimated at about 44,000 cubic feet per second, of which 1,000 is used for navigation and 43,000 for power development. The water is all returned to the St. Marys River just below the rapids, and consequently these diversions, even if uncompensated, would not, in the long run, affect the mean levels of the lower river or the lakes beyond. With conditions in the St. Marys River as they were in 1896, Lake Superior would have been lowered nearly 3 feet by the present diversions. That the surface of the lake has not been lowered by this amount has been due to obstructions placed in the channel and to the building of compensating works. At the same time any appreciable effects on the mean annual levels downstream have been prevented.

The building of the piers of the International Bridge in 1887 and the fills made along the bridge line, which closed some of the small channels among the islands on the north side of the river obstructed about 2,300 square feet of the cross-section of the river. In 1889 the power canal, constructed on the Canadian side, further obstructed about 1,600 square feet. In 1892 the dike built by the Chandler-Dunbar Water Power Co. for the Edison Sault power canal obstructed the flow through spans 1 and 2 of the bridge. These various obstructions undoubtedly raised the level of Lake Superior, but their

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effect can only be computed theoretically, as no measurements of the flow of the river were made until 1896. It appears probable that changes prior to 1896 had raised the level of Lake Superior about 0.7 foot. Diversions in 1896 were as follows:

	Cubic feet per second.
Navigation canals.....	400
Lake Superior Power Co.....	3,800
Chandler-Dunbar Power Co.....	1,065
Total.....	5,265

This diversion would lower Lake Superior by about 0.35 foot, leaving the lake level still three or four-tenths of a foot higher than it was before 1888.

In 1901 compensating works were constructed on the Canadian side of the river above spans 9 and 10 of the International Bridge. As the cofferdam above these gates was not removed until 1914, these works shut off most of the flow that formerly passed through spans 9 and 10.

In 1909 a series of measurements of the flow of the river was made from the International Bridge, and at the same time the flow through the various diversion canals was accurately determined. The diversions at that time were as follows:

	Cubic feet per second.
Navigation canals.....	650
Lake Superior Power Co.....	6,130
Michigan-Lake Superior Power Co.....	12,300
Chandler-Dunbar Power Co.....	980
Total.....	20,060

For a stage of 601.85 at the southwest pier gauge the total flow of the river in 1896 was 75,000 cubic feet per second. For the same stage in 1909 the total flow was 75,100 cubic feet per second. It appears therefore that between 1896 and 1909 the lowering of Lake Superior, due to diversions of water, had been almost exactly compensated by obstructions to the flow, and that the level of the lake was still some three or four-tenths of a foot above its normal for the period prior to 1888.

In 1911 the United States built a cofferdam above spans 3 and 4 of the bridge and a dike downstream from the north end of span 4, making a new headrace for the Government power plant. To compensate for the flow so obstructed sluice gates were erected along the lower end of the forebay. By the use of these gates the flow through these spans of the bridge can be maintained at a normal value unless the use of water through the power house should exceed the normal flow.

In 1914 the question of increased use of water for power purposes and the construction of compensating works was brought before the International Joint Commission of the United States and Canada. The commission approved a plan calling for putting into operating condition the four gates built in 1901 on the Canadian side of the river, the construction of 12 additional gates extending from the south end of the four built in 1901 to a point above pier 5 of the bridge, and the construction of a dike above span 5 connecting the end of the gates with the dike of the headrace of the United States power plant.

The eight gates above spans 6 and 7 of the bridge were built by the Michigan Northern Power Co. October, 1914, to September, 1916. Since the completion of these gates they have been operated under the direction of the board of control created in accordance with the order of the International Joint Commission for the purpose of regulating the level of Lake Superior and, so far as practicable, controlling the flow in the lower river in the interests of navigation.

The remaining four gates are now being built by Canadian interests above span 8 of the bridge. The construction of the proposed dike above span 5 awaits the completion of the power development on the Canadian side to the full proposed use of one-half the low-water flow.

When the compensating works are completed and the several power canals enlarged to their proposed capacity, it is expected that the needs of navigation can be served, a minimum of 60,000 cubic feet per second can be used for power and the level of Lake Superior can be regulated within a maximum range of 2.5 feet, and ordinarily within a range of 1.5 feet, or between elevations 602.1 and 603.6.

The compensating gates built in 1901-02 on the Canadian side of the river above span 9 of the bridge, now known as gates 1 to 4, consist of Stoney gates of steel, each 54 feet 3½ inches long, and 12 feet 11¼ inches high, lifting vertically between piers, having clear openings of 52 feet 3 inches. The gates are operated by hand from steel towers erected on the piers. The piers are of concrete with brick facing and cut-stone starling, coping, and quoins. They are 9 feet wide, 57 feet long, and 20 feet high. The sills are of oak, embedded in a concrete paving or apron. The elevation of the sills is 591.2 feet.

Compensating gates 9 to 16, completed and opened in September, 1916, above spans 6 and 7 of the bridges, are Stoney gates of the same type and dimensions as gates 1 to 4, with similar piers except that the latter are entirely of concrete. These gates are shown on photographs Nos. 169 and 170.

Compensating gates 5 to 8, now under construction above span 8 of the bridge, are of the same type and dimensions as the others except that the sills are at elevation 590.2 feet, or 1 foot lower than the other gates.

There are three sluice gates in the United States headrace, built in 1911, which form a component part of the compensating works. They are Stoney gates of the same general type as those described above, each 34 feet 4 inches long and 15 feet high, with a clear opening between piers of 33 feet. The piers are of concrete, 16 feet wide and 28 feet long. They are provided with steel-roller tracks. The sills at elevation 588.07 feet are of oak, 12 by 24 inches, set in the concrete apron, which is paved with vitrified brick. In connection with these gates there are two ice runs 16 feet wide with sills at elevation 598.07 feet, which are closed by stop logs supported by concrete piers. There is also an overflow weir of concrete 150 feet long with its crest at elevation 603.07 feet. These gates are illustrated in photographs Nos. 52 and 171.

Diversions from Lakes Michigan-Huron.—Aside from small sanitary diversions of purely local significance the only diversions from

Lakes Michigan-Huron are those of the Chicago Sanitary Canal and the Black River Canal at Port Huron.

Chicago Sanitary Canal.—The Chicago Sanitary Canal has been fully described in Sections A, B, and C of this report. Its mean diversion for the year 1917 was about 8,800 cubic feet per second. The construction of the Calumet-Sag Canal is nearly finished. An additional diversion of 2,000 cubic feet per second through this canal is proposed.

An ultimate diversion of 14,000 cubic feet per second through both channels is contemplated.

Diversions of water from Lake Michigan into the Mississippi Valley result in a lowering of all water levels of the Great Lakes from the lower sill of the locks at Sault Ste. Marie, down to tidewater in the St. Lawrence River. The amount of lowering on each lake as derived from discharge formula adopted by the Lake Survey office is shown in Table No. 46 for various amounts of diversions up to 14,000 cubic feet per second. The effect on the lower sills of locks at Sault Ste. Marie and in the lower St. Marys River is practically the same as for Lakes Michigan-Huron. The lowering at points along the St. Clair and the Detroit Rivers is somewhat less than for either Lake Huron or Lake Erie. Effects in the upper Niagara River decrease from Lake Erie to the Falls, amounting at Niagara Falls to about 60 per cent of the Lake Erie effect. In the St. Lawrence River the lowering effect varies considerably on account of the variety of cross-sections and slopes. The maximum above Cornwall is on the lower sill of Lock 25 of the Canadian canals, and this effect is given in the table. It is claimed that the effect of a diversion of 10,000 cubic feet per second at Chicago on the level of the water at Montreal is somewhat more than eight-tenths of a foot, but this has not been verified.

TABLE NO. 46.—*Lowering of lake levels in feet by diversion of water from Lake Michigan through the Chicago Drainage Canal.*

Amount of diversion at Chicago.	Lakes Michigan-Huron.			Lake St. Clair.			Lake Erie.		
	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.
2,000.....	0.10	0.10	0.10	0.08	0.08	0.08	0.10	0.09	0.09
4,000.....	.20	.20	.19	.16	.16	.16	.19	.18	.17
6,000.....	.30	.29	.28	.24	.24	.24	.29	.28	.26
8,000.....	.40	.39	.38	.31	.32	.32	.39	.37	.35
10,000.....	.50	.49	.48	.39	.40	.40	.49	.46	.44
12,000.....	.60	.59	.57	.47	.48	.48	.59	.55	.53
14,000.....	.70	.68	.67	.55	.56	.57	.69	.65	.61

Amount of diversion at Chicago.	Lake Ontario.			St. Lawrence River at Lock No. 25.		
	Low.	Mean.	High.	Low.	Mean.	High.
2,000.....	0.10	0.09	0.09	0.15	0.14	0.13
4,000.....	.20	.19	.18	.30	.28	.27
6,000.....	.30	.28	.27	.45	.42	.41
8,000.....	.40	.38	.36	.60	.57	.54
10,000.....	.50	.48	.46	.75	.71	.68
12,000.....	.60	.57	.55	.90	.85	.81
14,000.....	.70	.67	.64	1.04	1.00	.95

Elevations of the Lakes for the stages referred to in this table are as follows:

	Huron.	Erie.	Ontaro,
Low.....	579.6	570.8	244.5
Mean.....	581.1	272.8	246.0
High.....	582.6	573.8	247.5

Black River Canal.—The Black River Canal, at Port Huron, Mich., has been described in Section B of this report. Its diversion is estimated at about 400 cubic feet per second. The water is taken from Lake Huron, just above the head of St. Clair River, and is returned to the river a few miles downstream, at the mouth of the Black River. Such a diversion tends to cause a lowering of lakes Michigan-Huron and of the St. Clair River above Black River. The diversion, however, is so small that the effect is inappreciable. It is estimated to be about five thousandths of a foot or about one-sixteenth of an inch.

Diversions from Lake Erie—Welland Canal.—This important waterway has been described in Sections A and C. The estimated diversion in 1918 was about 4,500 cubic feet per second, of which an average of 900 was used for navigation and the rest for power and sanitary purposes. This diversion lowers Lake Erie and the Niagara River directly, and, by reducing the backwater on the connecting rivers, it lowers Lake St. Clair and Lakes Michigan-Huron. It has no effect on Lake Superior, Lake Ontario, or the St. Lawrence River. The effect on each lake is shown in Table No. 47.

Black Rock Ship Canal.—This canal is described in Section A. The estimated diversion is 700 cubic feet per second. As the water is returned to the Niagara River partly at the foot of Squaw Island and partly at Tonawanda the effect is limited to Lake Erie and Lakes Michigan-Huron. The magnitude of these effects is shown in Table No. 47. It seems probable that the construction of Bird Island Pier in 1823-1825, in connection with building the Erie Canal, caused a very appreciable rise in Lake Erie, but no data on this point exist.

New York State Barge Canal.—This canal is described in Sections A and C of this report. The present diversion is estimated at about 1,000 cubic feet per second. This water is diverted from the Niagara River and most of it eventually finds its way to Lake Ontario. The diversion causes a lowering of the upper Niagara River and has a slight effect on Lake Erie and Lakes Michigan-Huron. The magnitude of the effects is shown in Table No. 47.

Diversions at Niagara Falls.—Diversions of water for power purposes at Niagara Falls, above the first cascade in the upper rapids, lower the level of the water in the Grass Island-Chippawa pool. This lowering extends in diminished amount up the river. At Austin Street, Buffalo, it amounts to about one-fifth of the lowering at Chippawa. The effect of the lowering is the same as that produced by lowering the tailwater of a submerged weir, the flow of the river being increased for a given stage, which results in lowering the headwater, in this case, Lake Erie. Through the discharge measurements and water-level records of the Niagara River it has been determined that diversions at Niagara Falls, above the cascades, increases the

flow of the river for a given stage of Lake Erie by about 10 per cent of the amount of the diversions.

Diversions below the first cascade affect the depth of water between the point of withdrawal and the point at which the water is returned, but have no effect upon the levels above or below these points. The effects of the Falls and rapids have been fully described in Appendix C of this report.

The power plants on the United States side of the river both draw their water from above the first cascade. The present diversion through the Niagara plant of the Niagara Falls Power Co. is 9,450 cubic feet per second and that through the hydraulic plant of the same company is about 8,000 cubic feet per second. The diversion of the Ontario Power Co. is at the first cascade and does not have the full effect of an equivalent diversion from the Grass Island-Chippawa pool. Observations during the construction of the intake indicate that the effect is about 50 per cent of a like diversion from the pool. The present diversion by this company is probably about 11,200 cubic feet per second, or an equivalent of 5,600 cubic feet per second drawn from the Chippawa pool. The total present diversion from this pool therefore can be considered approximately 23,000 cubic feet per second. A diversion of this amount at mean stage would lower the Chippawa pool 0.59 feet and would increase the flow of the Niagara River 2,300 cubic feet per second, resulting in lowering the surface of Lake Erie 0.10 feet. This lowering, by increasing the flow through the St. Clair-Detroit River, would lower Lake St. Clair and Lake Huron by small amounts. The effects of the Niagara Falls diversions are given in Table No. 47.

Diversions from Lake Ontario.—There are at present no direct diversions from Lake Ontario nor from the St. Lawrence River above the Galop Rapids. The only diversions to affect the level of the lake are therefore those at Chicago, where the water is permanently withdrawn from the drainage basin. These effects, which are determined from the increments of outflow from Lake Ontario, are shown in Table No. 47.

It may be stated that the construction of the artificial dam closing the channel, known as "The Gut," at the head of Galop Rapids, which was built for the purpose of checking cross currents in the navigable channel of the river, has resulted in raising the levels of Lake Ontario at mean stage about 0.56 foot. This amount is about 50 per cent greater than the lowering caused by the present diversion at Chicago, so that in so far as the levels of Lake Ontario and of the St. Lawrence River above Galop Rapids are concerned, full compensation has already been effected. Below the Galop Rapids the levels of the St. Lawrence are affected by the Chicago diversion, and, in addition, there are small uses of water for power purposes along the Canadian canals and at Waddington, N. Y., and a large diversion at Massena, which have local effects extending from short distances above the points where the water is withdrawn to where it is returned to the river.

TABLE NO. 48.—*Effect, in feet, at mean stage of proposed diversions from the Great Lakes.*

Diversion.	Proposed increase.	Lake Michigan-Huron	Lake St. Clair.	Lake Erie.	Niagara River at Chippewa.	Lake Ontario.	St. Lawrence River at Lock 25.
Chicago Sanitary Canal.....	5,200	0.25	0.21	0.23	0.13	0.24	0.37
Welland Canal.....	1,000	.01	.02	.05	.03	.....	.....
New York State Barge Canal....	700	.....	.....	.01	.02	.....	.....
Niagara Falls Power Co.....	48,000	.03	.10	.22	1.25	.....	.....
Total effect of proposed increases.....	.....	.29	.33	.51	1.43	.24	.37
Total effect of present diversions.....	.....	.47	.50	.76	.98	.42	.63
Sum.....	.....	.76	.83	1.27	2.41	.66	.99

7. REMEDIAL WORKS.

Practically all the commerce of the Great Lakes originates or terminates in improved harbors or passes en route through improved canals or channels where the draft of vessels is limited by the depths to which these harbors and channels have been improved. The larger vessels of the lake fleet are designed and built to utilize the full depths provided by the improvements. It is obvious that any lowering of the lake surfaces will decrease the limiting depths and consequently lessen the carrying capacity of the lake fleet. For this reason the diversions have caused and are now causing a serious loss to the commerce of the Great Lakes, the nature and extent of which is discussed in Section H 1 of this report.

There are three general methods by which a restoration of depths on the lakes may be sought, namely, first, the deepening of all harbors and channels affected by the artificial lowering of water levels; second, the construction of regulating works in the outlets of the lakes to raise the levels of the lakes and to control them within fixed limits; and, third, the contraction of the outlets by means of fixed obstructions which will raise the levels of the lakes without greatly affecting their natural fluctuations.

The first method requires a large amount of dredging and the reconstruction of several locks. In 1907 the International Waterways Commission estimated that the cost of restoring harbor and channel depths in the United States and Canada to care for a diversion of 10,000 cubic feet per second through the Chicago Drainage Canal would be \$12,500,000. At present prices this figure would be largely increased. No estimate of such restoration has been made in this investigation for the reason that the use of remedial works is considered much more satisfactory and very much less expensive. Furthermore, deepening the river channels tends to increase the discharge of the lake above and thereby lower its level, thus increasing to some extent the undesirable condition which it is intended to overcome.

The Board of Engineers on "Deep waterways between the Great Lakes and the Atlantic tidewaters," in its report of June 30, 1900, House Document No. 149, Fifty-sixth Congress, second session, presented a plan for the regulation of Lake Erie between fixed levels by works at the head of Niagara River. It was proposed to build a

combination of submerged weirs and stoney gates, by means of which Lake Erie was to be raised about 3 feet above the low-water level and held continuously within about 0.6 foot of the adopted level. The impossibility and also the undesirability of such regulation are clearly shown in a report of the International Waterways Commission, House Document No. 779, Sixty-first Congress, second session. The water supply of this lake is so extremely irregular that its amount can not be predicted with any degree of certainty, and without advance knowledge of the supply close regulation can not be maintained.

Any great variation above the proposed level would cause serious damage on low-lying lands adjoining the lake, particularly in the vicinity of Buffalo, where the fluctuations due to wind are now as much as 8 feet. Other objections expressed in House Document No. 779 are that the regulating works would aggravate ice jams at the head of the Niagara during the winter season, thereby causing greater fluctuations in water levels at Buffalo with consequent damage to property, and that the closed season at Buffalo would be prolonged by the holding back of ice fields in the spring which otherwise would pass down the river.

It is possible to regulate Lake Erie within a larger range than proposed by the Board of Engineers on Deep Waterways, and if the capacity of the river were enlarged at low-water stage the regulated level could be lower. This, however, would not obviate the probable troubles with ice, and the regulation would so change the outflow from Lake Erie as to be detrimental to levels of Lake Ontario and the St. Lawrence River. Regulation of the level of Lakes Michigan and Huron, if feasible, would better conditions on those lakes and in the lower St. Marys River, but the change in outflow caused by such regulation would likewise increase the fluctuations in the lower lakes and rivers to the detriment of navigation. Moreover, the construction of regulating works in the St. Clair River must of necessity cause a serious obstruction to navigation.

A study of hydraulic conditions on the Great Lakes shows clearly the close interdependence of their levels and the system by which nature regulates those levels. Whether the system can be improved upon by human agency sufficiently to justify the construction and operation costs is problematical. Any change involving artificial storage to be generally beneficial would require cooperative regulation of all of the lakes and rivers, with an intricate system for balancing the variable and erratic supply from the various drainage basins. Such regulation would involve tremendous costs and the whole works would be more or less experimental.

It is quite possible that regulation will ultimately be resorted to when the various interests about the Great Lakes have become more valuable and when experience, experiment, and further study have indicated more certainly its desirability. In such case regulation of Lake Ontario and the St. Lawrence River would possibly best be undertaken first.

On the other hand, it is perfectly feasible to raise the surface of any of the lakes without interfering appreciably with its natural fluctuations or its average monthly flow, and hence without affecting levels on the lakes and rivers below. This is illustrated by the

artificial raising of Lake Ontario, caused by the construction of the "Gut Dam"; where, however, the building of this dam above low-water level has decreased the increment of discharge and increased to some extent the fluctuations on Lake Ontario.

In the report of a special board of engineers upon waterway from Lockport, Ill., to the mouth of Illinois River, House Document No. 762, Sixty-third Congress, second session, are presented plans for compensating the levels of Lakes Erie, Michigan, and Huron for a diversion of 10,000 cubic feet per second at Chicago. These plans propose the construction of three submerged weirs in the upper Niagara River near Squaw Island and a series of six weirs in the St. Clair River, spaced one-half mile apart over a stretch extending downstream some 3 miles from the mouth of Black River. These weirs are 4 to 6 feet high and are designed to raise Lake Erie 0.45 foot or 5.4 inches, and Lakes Michigan and Huron 0.47 foot or 5.6 inches. The estimated cost is \$475,000, with a possible annual expenditure of \$15,000 for maintenance. These estimates are based on prices of labor and materials much lower than now obtain.

That this method of compensation is practicable and that the desired results can be obtained at a comparatively reasonable cost is beyond question. Furthermore, structures of this nature would offer a minimum interference with navigation and would have little tendency to retard the movement of ice.

To compensate for the loss of elevation on water levels above the head of Niagara River resulting from all diversions, present and prospective, would require, as shown in Table No. 48, the raising of Lake Erie 1.27 feet, Lake St. Clair 0.83 foot, and Lakes Michigan and Huron 0.76 foot. This would necessitate much more extensive works than those planned in the report just referred to; and because of the amount of back water required and the limiting sections in which to work, it might be necessary to adopt additional means of contracting the channels than by weirs alone.

There is a wide range in the matter of details and locations of compensating works that would be practical and would give the full compensation desired. The selection of the best and most economical method is largely a matter of engineering judgment.

St. Lawrence River.—The diversion at Chicago is the only one which lowers the whole St. Lawrence River. At mean stage the lowering due to a diversion of 14,000 cubic feet per second is 0.66 foot at the head of the river and the effect is practically unchanged as far down as Ogdensburg. Below Ogdensburg the river is a succession of rapids and pools, and the amount of lowering changes greatly from point to point. The value of 0.99 foot at Lock 25 is the greatest that has been computed for any point above St. Regis, although it is possible that a slightly greater effect may exist at some other point. Below St. Regis the stream flows entirely through Canadian territory, and detailed hydraulic data is not available. It is said that at some places in this part of the river the lowering is 15 or 20 per cent greater than at Lock 25. Below Montreal there are no rapids and the slope is small. The effects of diversion in this part of the river decrease toward the ocean.

In this investigation no consideration has been given to the matter of compensating works downstream from St. Regis. For the reach between St. Regis and Ogdensburg the data is very scanty and any

detailed study would require extensive surveys. The traffic on the St. Lawrence is comparatively small, being less than 5 per cent of the traffic on the upper lakes, and only about one-third of this is in United States vessels. For these reasons it was not thought advisable to make a detailed study of compensating works on the St. Lawrence River. In general, it can be said that such works are entirely feasible and present no especial difficulties of construction. At the head of each rapids an obstruction of some sort must be built, probably in the nature of a narrowing of the river. This will raise the water in the pool above. The increased velocity caused by the obstruction will do no damage, as there is no upbound navigation in any of the rapids, and the bottoms of all are composed of ledge rock or large boulders which would not be subject to erosion by the moderately increased velocities.

Proposed works at Ogden Island.—The New York & Ontario Power Co. is promoting a scheme for developing power in the "Little River" behind Ogden Island by rebuilding the old dam, removing the causeway, and enlarging the entrance channel, as explained in Section C. To compensate for the lowering of more than 2 feet, which the proposed diversion of nearly 30,000 cubic feet per second would cause in the pool between Lock 24 and Lock 25, the company proposes to build a training wall between Canada Island and the foot of Ogden Island, and also to construct a submerged weir between Ogden Island and the head of the Morrisburg Canal. The depth of water on the weir is to be 22 feet at low stage. Detailed plans of the proposed works are not available, but it is believed that sufficient compensation is not provided. The project is now before the International Joint Commission for investigation.

Lake Ontario.—Fluctuations of stage are practically the same in Lake Ontario and in the St. Lawrence River above Ogdensburg, and in studies of this nature this part of the river can be considered to be merely an arm of the lake.

It is required to raise the level of the lake 0.66 foot. The building of the Gut Dam has already caused a rise of 0.56, and it is very doubtful if compensation for the remaining tenth of a foot is worth while. If it is desired, it merely requires a further obstruction at the head of the American channel of the Galop Rapids. Because of lack of data on slopes and velocities at this point no definite plan or estimate can be formulated, but it is apparent that nothing extremely elaborate or expensive would be required.

Niagara River.—The restoration of levels in Lake Ontario will also compensate for the lowering of the navigable portions of the Niagara River below the Falls.

On the upper river it is required to raise the level 2.41 feet at Chippawa. This can be done by an obstruction above the first cascade. On the Canadian side this obstruction should be placed below the mouth of Chippawa Creek in order to maintain the full head on power plants drawing water from this creek and to preserve the navigable depth in it. For similar reasons the American end of the obstruction should be below Port Day. The preservation of the beauty of the American Falls requires that little or none of the obstruction should be so placed as to obstruct the channel approaching the American Rapids. This matter is treated more fully in

Section E 3 of this report. These considerations indicate that the obstruction should extend from below Chippawa Creek north to within perhaps 1,500 feet of Port Day and then west to the head of Goat Island.

With the construction of new Niagara power plants large amounts of excavated rock will be available. It might fairly be required as one of the conditions of the permits for water diversion that the companies place part of this rock in the river at designated spots. The required amount can easily be determined by trial if water gauges are maintained at Chippawa and Buffalo. The cost to the Government would be only that of inspection and supervision.

It should be stated that during the past year material dredged from the new approach channel to Port Day has been dumped below the Port Day-Chippawa line and that this has raised the water level at Port Day. Study of the gauges shows that the effect of such dumping prior to March, 1919, has been to raise the water at Port Day about half a foot. This compensates for nearly one-half of the lowering which has thus far occurred at this point. It compensates fully for all the lowering caused by the American power companies. Spoil is being deposited similarly on the Canadian side by the Hydro-Electric Power Commission of Ontario.

The obstruction described in the preceding paragraph would in a measure be similar to the submerged rock weir described on page 34, House of Representatives Document No. 762, Sixty-third Congress, second session. It would be somewhat less regular in form, and would not extend across the channel leading to the American Falls. Moreover, it would be a less pretentious and expensive weir than the concrete weir proposed by the International Waterways Commission in Senate Document No. 118, Sixty-third Congress, first session, and would raise the Chippawa-Grass Island pool 80 per cent as much. Its location is less objectionable than that of the commission's weir, being downstream from Chippawa Creek and Port Day. It is also less objectionable, in that it will not cause as high water, and therefore will not flood low-lying lands in the vicinity. The weir advocated by the commission was designed to create a generous backwater effect on Lake Erie, while the obstruction herein proposed is designed to care for the Niagara River only, the submerged weirs near the head of the river creating the necessary backwater effect on the lake.

Lake Erie.—Works which raise the Niagara River 2.41 feet at Chippawa will cause a backwater effect at Austin Street sufficient to produce a rise of 0.42 foot in Lake Erie. As the total lowering of Lake Erie caused by the present and prospective diversions is 1.27 feet, works must be built near the head of the river sufficient to produce a further rise of 0.85 foot in the lake.

Hydraulic studies showed that this could be accomplished by five submerged dikes or weirs built across the river abreast of Squaw Island. The first would be located 4,450 feet above the International Bridge and the fifth 2,150 feet below it, the other three being spaced evenly between them. At these sections the river is from 1,770 to 2,350 feet wide, with maximum depths of from 34 to 45 feet at mean stage, and with mean velocities of from 4 to 4.8 feet per second.

There is very little navigation in this section of the river, as the greater number of downbound vessels and practically all upbound vessels use the Black Rock Canal and lock. The most restricted section is at the old waterworks intake about 8,000 feet above the bridge. Here the greatest depth is 13 feet at standard low water and the mean velocity is about 9.1 feet per second. No serious obstruction to navigation will occur if the depths and velocities at the compensating works are kept within these limits.

The works actually designed consist of rock dikes 15 feet wide on the crest with 2 to 1 side slopes. Their crests are 15 feet below standard low water. Near one shore the dike is higher, extending to within 6 feet of the surface at standard low water. This high part is on the American side in the two upstream sections and on the Canadian side in the other three. Its length varies from 67 to 767 feet. The mean velocity over each of these dikes is 8 feet per second at mean stage. It will be observed that any vessel which can pass the waterworks intake safely will have no difficulty in passing these works. Ice and drift will pass freely.

The bottom and Canadian shore of this part of the river consist of ledge rock and large boulders and will not be subject to scour. Near the Squaw Island end of each dike protection against scour will be needed as the material there is sand, gravel, and clay.

The estimated effect of these works is to raise the river 1.9 feet at the upstream weir and to raise Lake Erie 0.85 foot. The hydraulic problems involved are very complex and do not admit of an exact solution. Several different methods of computing the effect have been tried and their results compared. It is believed that the figures given above are reasonable, erring, if at all, upon the side of safety. When the works are constructed the effect can be closely watched by gauge comparisons and the desired amount of compensation can be obtained by small changes in the original plans.

The weirs as designed contain about 185,000 cubic yards of material. The cost is roughly estimated at \$2,000,000.

Detroit River.—When Lake Erie is raised 1.27 feet by the two sets of compensating works in the Niagara River, which have just been described, Lake St. Clair will be raised 0.55 foot. As the total lowering of Lake St. Clair by the present and prospective diversions is 0.83 foot, there remains 0.28 foot to be compensated for in that lake. The further compensation needed on the Detroit River varies from 0.28 foot at the upper end to zero at the mouth. In the dredged channels in the lower part of the river the lowering would not exceed one-tenth of a foot. This could be compensated for by an obstruction west of Grosse Isle, but only at the expense of increasing the current through the channels where the present current causes considerable annoyance to vessel men. As the lowering is very small, it will probably be most satisfactory to leave it uncompensated.

From the foot of Fighting Island to the head of the river the resultant lowering will be from 0.10 to 0.28 foot. As the depths are ample in this part of the river, there is no need for any compensation.

Lake St. Clair.—There are several methods by which Lake St. Clair can be raised the required amount of 0.28 foot. It is important that this compensation should be complete, for Lake St. Clair is now the point of limiting depth in the Great Lakes waterway, and any shoaling there has very serious effects.

Submerged weirs in the deeper sections of the Detroit River below Belle Isle could be designed to produce the required effect, but would be somewhat objectionable on account of the increased and variable currents that would be created along the busy dock front of Detroit. Another plan would be the partial closing of the channels on the American side of Belle Isle and the Canadian side of Peche Island, with such additional contraction of the main channel as might be required. The channel north of Belle Isle is seldom used by anything but pleasure craft, and might well be closed except for a narrow channel which would permit the passage of the smaller boats, ice, and sufficient water to keep the American channel clean. To avoid unsightliness, a dam in this locality should be below low water or be built as an artistic causeway from the head of the island to the mainland. The principal objection to this plan is the danger that the increased velocities would scour the soft bottom of the main channel and thus lessen the compensation.

The full details and estimates of compensating works in the Detroit River are not possible with the data now available, nor is it possible, without a special survey and a thorough study of conditions, to say that a plan can be devised that will not be subject to serious objections.

An alternative and probably a better and cheaper method of restoring depths in Lake St. Clair would be by dredging of the channels 0.28 foot deeper. This additional dredging would require the moving of about 800,000 cubic yards of material at a cost of perhaps \$160,000.

St. Clair River.—If compensating works on the Detroit River are omitted and the depths in Lake St. Clair are restored by dredging, the rise in Lake St. Clair caused by the Niagara works will be 0.55 foot. This will cause a rise in Lake Huron of 0.16 foot. The uncompensated lowering will be 0.28 foot in Lake St. Clair and 0.60 foot in Lake Huron. In the St. Clair River the lowering will be between these limits.

On the St. Clair River below Port Huron there are a number of small towns and villages on both sides of the river. These have docking facilities for vessels drawing from 10 to 15 feet of water. The actual navigation at these ports is very small and the damage resulting from a small reduction in the available depths would be trifling. In any particular place a small amount of dredging would restore the original depth if it were thought worth while.

There are also a few places where the main ship channel has been deepened by dredging and where a little additional dredging might be required to maintain the project depth. It is estimated that this dredging would not cost more than \$50,000.

At the head of the river the cities of Port Huron, Sarnia, and Point Edward are all important ports used by vessels of the larger type. The matter of maintaining the depths at these ports need not be discussed here, as the project suggested in the next paragraph for compensating Lake Huron will do all that is needed.

Lake Huron.—To raise Lake Huron 0.50 foot by means of compensating works near the head of St. Clair River would require contraction of this outlet sufficient to hold back about 15,000 cubic feet per second of flow at mean stage, or nearly 8 per cent of the natural discharge.

It is believed safe to assume that a minimum depth of 25 feet at standard low water and a maximum velocity of $4\frac{1}{2}$ feet per second would in no way prove detrimental to navigation. It is practicable to provide the compensation and to keep within the limits named by improvements in the St. Clair River below the mouth of Black River. A series of submerged weirs with crests 25 feet below low water would serve the purpose. It is estimated that 11 sets of weirs spaced about one-third of a mile apart and containing a total of about 290,000 cubic yards of stone, will raise the level of the river above the upper weir an amount sufficient to back up Lake Huron the full amount required. Bank protection would be required at the ends of the weirs. The cost would probably not exceed \$1,500,000.

The preceding discussion of compensating works on the various rivers is based upon the idea of compensating for the greatest diversions that are now seriously contemplated. If it should be definitely decided that some of these diversions shall be limited to smaller amounts than those considered here, the magnitude and cost of the works would be correspondingly reduced.

It has been pointed out that the construction of such works ought to be a tentative process. A certain amount of work should be done and the effect observed. Then more work added, and so on, until the required amount of compensation has been secured. For this purpose it is highly desirable that a number of automatic water gauges be installed at the critical points on the various rivers. These should preferably be installed several years before the work is undertaken and maintained continuously until long after it is completed. The gauges now maintained by the Buffalo and Detroit engineer districts and by the Lake Survey will be of great value for this purpose but will be quite insufficient. They need to be supplemented by additional gauges, and it is important that such additional gauges be installed long before the proposed work is undertaken.

Several proposals not here discussed have been made for regulating certain lake levels or for compensating them. Compensation without regulation is effected by fixed works which contract the outflow stream at the bottom or the sides or both. Contraction at the sides tends to increase fluctuations of level in the pool above with changes of discharge through the outlet. For this reason such works have been avoided as much as possible in the projects presented above, although they are somewhat simpler, and are frequently suggested. The term controlling works denotes movable structures which may be closed to effect compensation, and opened to lessen or eliminate it. Such are the Stoney gates at the Soo, and those planned for the head of Niagara River by the Board of Engineers on Deep Waterways.

A proposal has been made to place several somewhat similar gates of large size within the head of Niagara River not far above the International Bridge, extending only part way across the river. Plans for these works are presented in the House Document No. 762, Sixty-third Congress, second session, page 35. It was proposed to operate these gates so as to reduce the night flow and increase the daylight flow of Niagara River, as well as permanently to raise the level of Lake Erie. Somewhat similar gates have been proposed for the St. Lawrence River, with a view to holding up the levels of that



Photograph No. 168.—INTERIOR OF TRANSFORMER STATION. NIAGARA FALLS POWER CO.



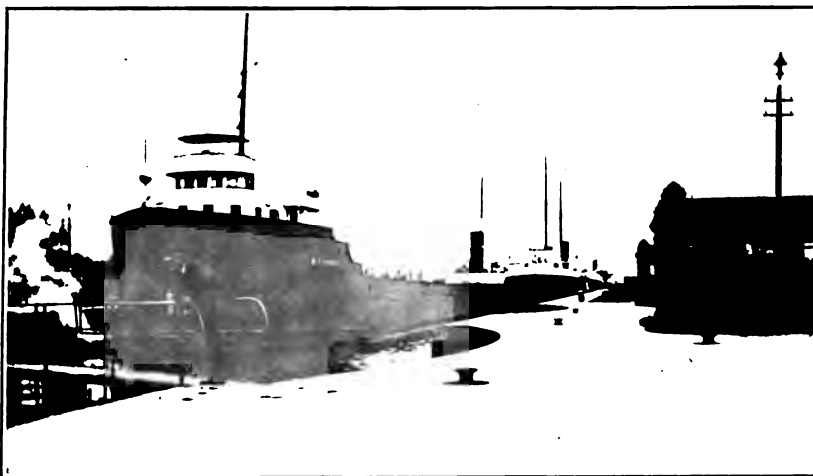
Photograph No. 169. COMPENSATING WORKS IN ST. MARYS RIVER.



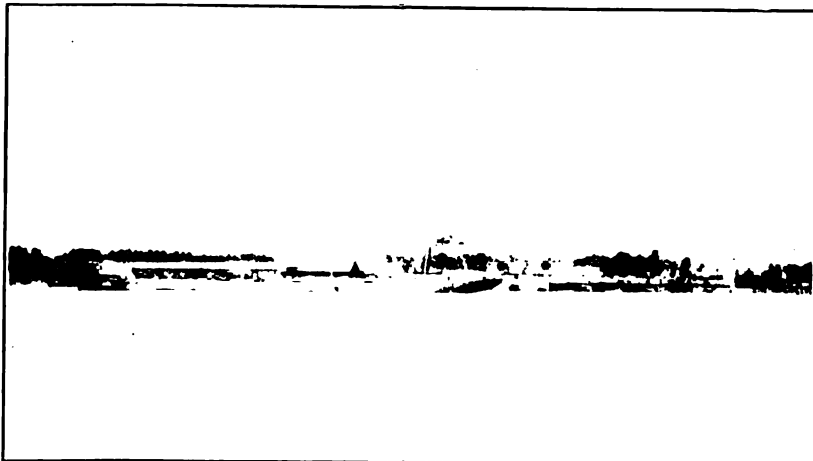
Photograph No. 170.—COMPENSATING WORKS IN ST. MARYS RIVER.



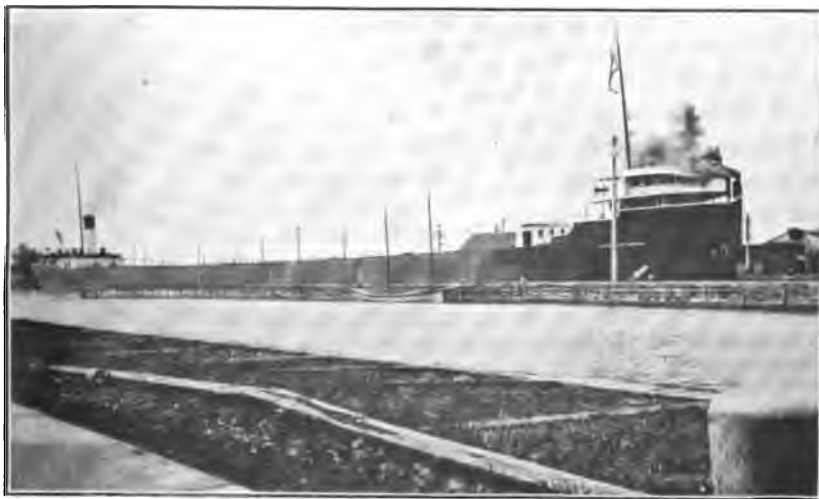
Photograph No. 171. COMPENSATING SLUICES AT GOVERNMENT POWER HOUSE, ST. MARYS RIVER.



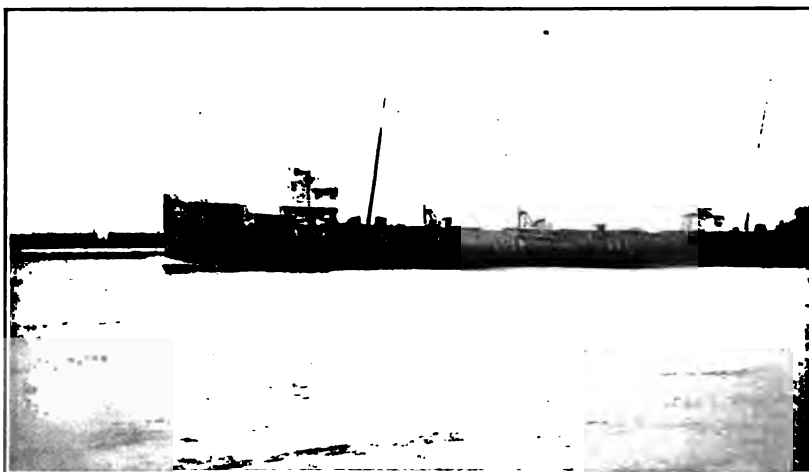
Photograph No. 172.—STEAMER "B. F. JONES" IN THE POE LOCK.
Length, 530 feet; breadth, 56.2 feet; depth, 32 feet; gross tonnage, 6,939.



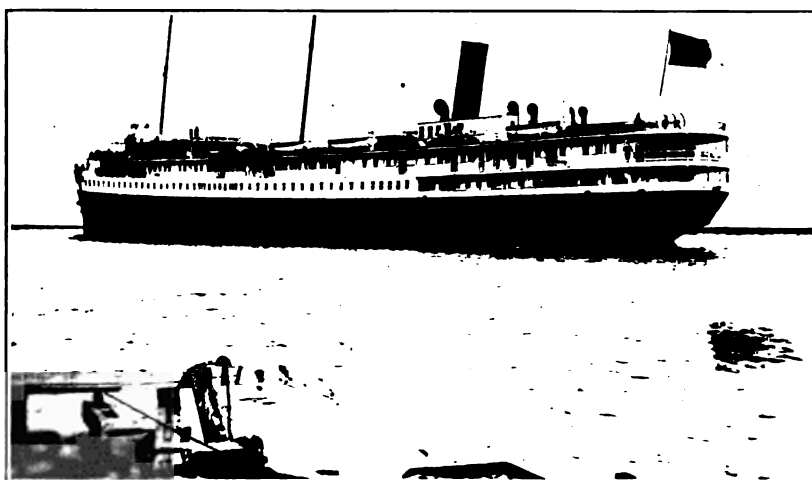
Photograph No. 173.—STEAMER "B. F. JONES" IN ST. CLAIR RIVER.



Photograph No. 174.—STEAMER "J. PIERPONT MORGAN" ENTERING POE LOCK.
Length, 580 feet; breadth, 58 feet; depth, 27.4 feet; gross tonnage, 7,161.



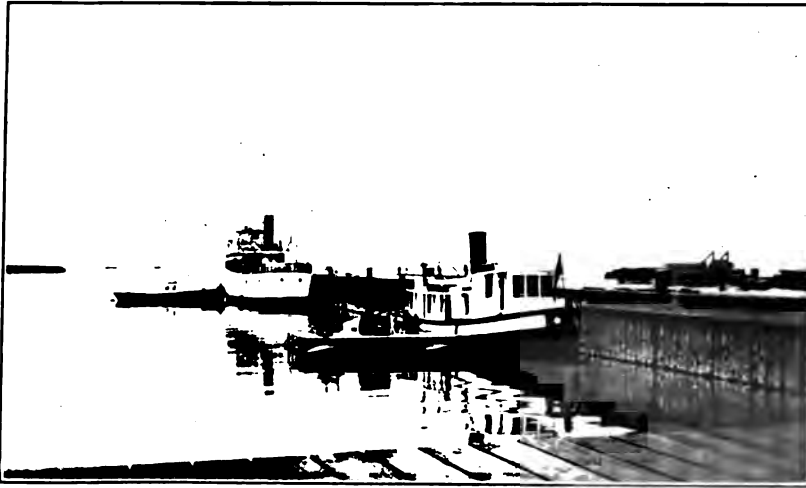
Photograph No. 175.—ICE-COVERED PACKAGE FREIGHTER IN ST. CLAIR RIVER.



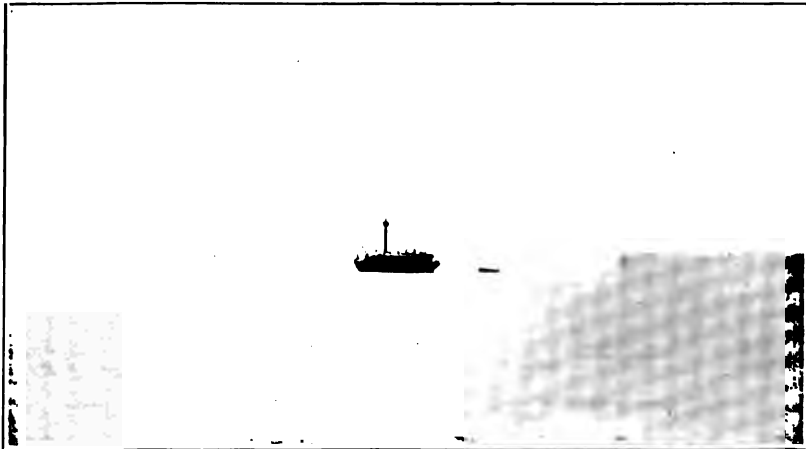
Photograph No. 176.—PASSENGER STEAMER "TIONESTA" IN ST. CLAIR RIVER.
Length, 340 feet; breadth, 45.2 feet; depth, 28 feet; gross tonnage, 4,329.



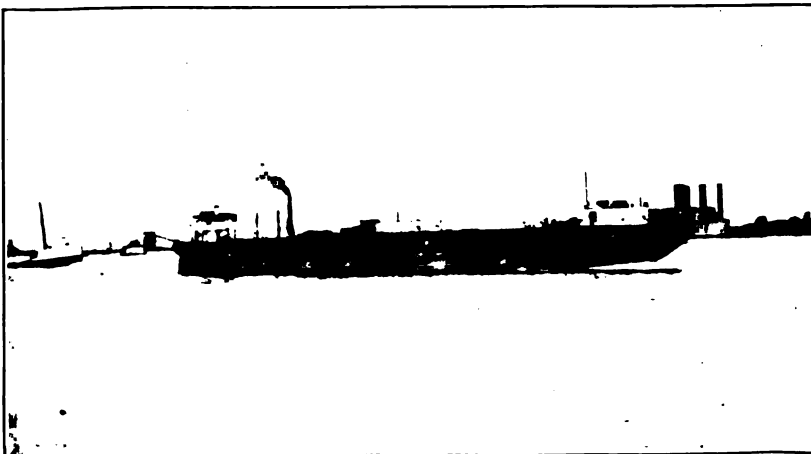
Photograph No. 177. —PASSENGER STEAMER "NORTH WEST" IN ST. CLAIR RIVER.
Length, 358.5 feet; breadth, 44 feet; depth, 23.2 feet; gross tonnage, 4,244.



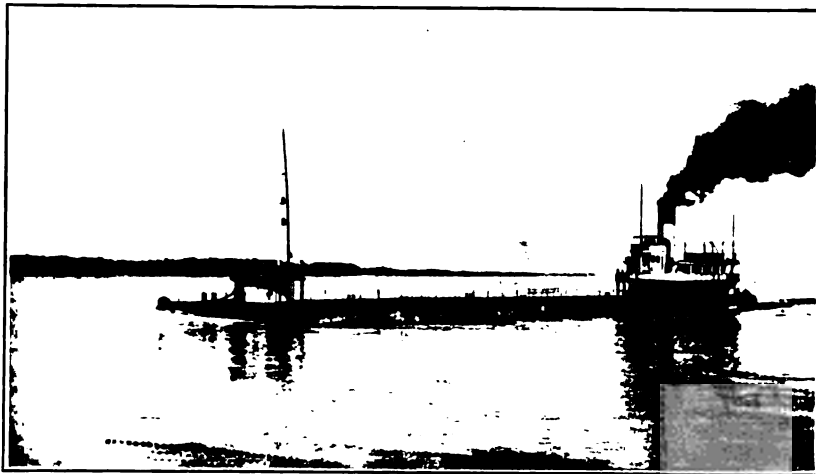
Photograph No. 178.—GOVERNMENT SURVEY STEAMERS IN CLEVELAND HARBOR.



Photograph No. 179.—LIGHTSHIP IN LAKE ST. CLAIR.



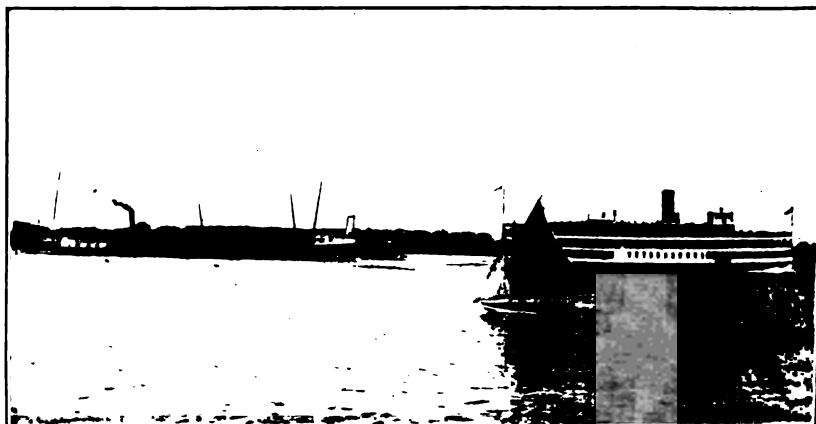
Photograph No. 180.—A WHALEBACK OR "PIG," LIGHT



Photograph No. 181.—A WHALEBACK, LOADED.
This interesting type is now obsolete and fast disappearing.



Photograph No. 182.—EXCURSION STEAMER "TASHMOO" IN ST. CLAIR RIVER.
Length, 302.9 feet; breadth, 37.6 feet; depth, 13.6 feet; gross tonnage, 1,344.



Photograph No. 183.—TWO FREIGHTERS, PASSENGER STEAMER, AND YACHT
PASSING IN DETROIT RIVER.

river and Lake Ontario, and also of diminishing the flow of the St. Lawrence, when the Ottawa River is in flood, and increasing it when the Ottawa is low. While such regulations of river flow may be found desirable in the future, it is believed that the time has not arrived when projects for such regulation need to be discussed or their practicability studied. Accordingly, in this investigation no serious consideration has been given them.

In the preceding paragraphs the intent has been to indicate in a general way the character and costs of works which seem most practicable for restoring and maintaining lake and river levels in the Great Lakes Basin. Surveys of sites and further study and design of works are necessary before construction is undertaken. It is believed that experiments upon large-sized models of sections of the rivers and the controlling works would lead to improvements in design fully justifying the expense.

The works herein estimated have been designed to care for the full effects not only of present diversions but of proposed diversions. The intention is to compensate for losses of level, and not to raise levels above normal elevations. Accordingly the works should be installed a portion at a time, so that the parts completed at any given time will compensate only for the effects chargeable to diversions existing up to that time.

W. S. RICHMOND.

APPENDIX F.

ECONOMIC VALUE OF DIVERSIONS.

[Section H of Mr. Richmond's report.]

1. EFFECT UPON NAVIGATION.

The lowering of the lake levels, discussed in Section G of this report, causes a loss to the community by decreasing the load draft of the Great Lakes shipping and thereby increasing the cost of transportation. The principal loss is in higher freight rates imposed to offset decrease of revenue to the vessel owners due to less amount of cargo carried on each trip of the deep-draft vessels. An attempt will be made to evaluate the loss caused by a lowering of one-tenth of a foot.

The interlake navigation channels, as improved and maintained by the United States, are now actually 20 to 22 feet deep at low-water datums, 2 feet below the mean levels of Lakes Michigan-Huron, and 1 foot below the mean level of Lake Superior. They may be enumerated as follows: Interlake channels, St. Marys River, approach above canals and locks; St. Marys Falls Canals and Locks; St. Marys River, channels and approaches below locks; Grays Reef Passage, Lake Michigan; Lake Huron, at head of St. Clair River and St. Clair River; Lake St. Clair, and Flats Canals; Detroit River.

The entrances to the terminal or principal harbors, as improved and maintained by the United States, are of corresponding depths. There are about 27 harbors where railroad connections and terminal facilities have been developed and where interlake commerce is carried on in vessels drawing 19 feet or more of water. The most important of these are listed in Table No. 49, which also shows the total receipts and shipments from each port for the year 1917.

TABLE NO. 49.—*Total receipts and shipments of freight for important ports of the Great Lakes in 1917.*

	Short tons.
Lake Superior:	
Duluth-Superior	52,411,824
Two Harbors (Agate Bay)	10,773,241
Ashland	9,580,085
Presque Isle (Marquette Bay)	2,801,312
Ports on the Keweenaw waterway	2,183,274
Marquette	1,191,024
Lake Michigan:	
South Chicago (Calumet Harbor)	10,269,304
Milwaukee	6,802,864
Indiana Harbor	2,209,165
Chicago	1,900,687
Lake Huron:	
Calumet	4,188,285
Lake Erie:	
Buffalo	18,925,179
Ashtabula	15,992,388
Cleveland	14,282,687
Toledo	13,710,238
Conneaut	12,936,293
Lorain	7,529,081

Lake Erie—Continued.

	Short tons.
Erie	4, 252, 810
Sandusky	4, 067, 249
Huron	3, 833, 358
Fairport	3, 461, 813

None of the other deep-draft ports have a freight traffic amounting to 1,000,000 tons per year.

Other lake harbors are of secondary importance. Their rail and terminal facilities or their location with reference to the source of supply or destination of bulk freight are such that their through commerce at the present time is inconsiderable. These harbors, which may be called local harbors to distinguish them from the interlake harbors, are used for many classes of local traffic by different sizes of vessels, and the classes of such traffic and the sizes of such vessels are subject to changes ranging from radical increases to marked decreases or even elimination. It has appeared impracticable to establish any standard depth for such local harbors. It must be understood that these harbors perform a very necessary purpose in handling local traffic, but the existing depths in the main ship channels are ample to accommodate all this commerce, and it is carried on by vessels of lesser draft than those carrying the great bulk of the through freight.

Load draft is primarily controlled by natural seasonal fluctuations of lake levels, which consist, in general, of—

On Lakes Michigan-Huron, and Lake Erie: A rise in March to June; high stage, July to September; fall, in October to December; lowest stage in January to February (navigation closed); range from 1½ feet below to one-half foot above mean lake level.

On Lake Superior: A fall, in March to April, to lowest stage (navigation being opened); rise in May to August; high stage in September and October; fall in November to February; range from three-fourths foot below to one-half foot above mean lake level.

The draft of vessels in the interest of avoiding damage to vessels by grounding, as affecting insurance, and the accomplishment of transportation of the estimated amount of bulk freight to be delivered during the season, is regulated to a large extent by notices of recommended drafts, issued by the Lake Carriers' Association, as shown in Table No. 50.

TABLE NO. 50.—Recommended draft for Lake freighters, 1917.

Date recommended.	Draft.	Elevation of water level.
		<i>Fect.</i>
April.....	20 feet for Lakes St. Clair and Erie.....	572.6
June.....	20 feet 4 inches for Lake Michigan; 20 feet 2 inches for Lakes St. Clair and Erie.....	573.6
Aug. 23.....	20 feet 10 inches for Lakes St. Clair and Erie.....	573.6
Sept. 5 to end of season.	21 feet 10 inches for Lakes St. Clair and Erie.....	573 to 3 572.6
1918.		
Apr. 9.....	21 feet for Lake Michigan.....	581.4
Apr. 21.....	19 feet 6 inches for Lake Superior.....	601.5
June 6.....	20 feet 6 inches for Lake Superior.....	601.7
Do.....	21 feet 6 inches for Lake Michigan.....	581.6
Do.....	20 feet 6 inches for Lakes St. Clair and Erie.....	572.2
Oct. 17.....	20 feet for Lake Superior.....	602.5
Do.....	20 feet for Lake Michigan.....	581.2
Do.....	20 feet for Lakes St. Clair and Erie.....	572.3

TABLE No. 50.—*Recommended draft for Lake freighters, 1917*—Continued.

Date.	Buffalo Harbor.				Ashtabula Harbor.	Conneaut Harbor.
	Donner Steel Co.	Above Ohio Street bridge.	Lehigh Valley and inside docks.	Lake front docks.		
Apr. 17.....	<i>Ft. in.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>
May 9.....	18 6	19 3	19 4	19 6	20 6	19
June 7.....				20 6		20 6
June 13.....			19 8			
July 1.....			20 3			
Oct. 17.....	19	19	20	20	20	20

No recommendations are issued for harbors at Cleveland, Lorain, Huron, Sandusky, or Toledo.

It will be noted that the above recommended drafts for the inter-lake waterway are not uniformly consistent with rise and fall of water level, and it is to be stated that these four harbors, especially Buffalo Harbor, indicate the influence of inner harbor conditions upon load draft.

Nearly all of the "bulk freight" traffic of the upper lakes is carried in large vessels of from 3,000 to 15,000 short tons cargo capacity. The vessels habitually load to a draft of 19 feet or over, depending upon the available depth. They carry the greatest possible load which they can get over the critical points in their journey, and every lowering of the lake level deprives them of that much carrying capacity.

The following study of the effect on this traffic of one-tenth of a foot lowering of lake level is based upon data contained in the Statistical Report of Lake Commerce Passing Through Canals at Sault Ste. Marie, Mich., and Ontario, the List of Merchant Vessels of the United States, and the Annual Reports of the Lake Carriers' Association.

Since the building of the first 500-foot vessel, the *Augustus B. Wolvin*, in 1904, of the ships expressly built for the bulk freight trade of the upper lakes only one has been less than 400 feet in length. The fleet now consists of 530 vessels with a total cargo capacity of 3,900,000 short tons for a single trip. This fleet may be approximately classified as to size as in Table 51.

TABLE 51.—*Classification of Lake freighters by size.*

Typical dimensions.		Number of vessels in class.	Cargo capacity, short tons, at 19 feet draft.	Increase of capacity, in short tons, per 0.1 foot of draft.	Percentage of total yearly freight carried.	Registered tonnage.
Length over all.	Beam.					
280	40	85	3,000	31	10	2,400
370	45	124	5,500	47	10	3,500
460	52	158	7,500	68	34	5,100
570	56	121	10,500	92	26	6,800
600	60	42	12,000	104	20	7,700

As Table 51 shows, at the ordinary load draft the effect of a reduction of one-tenth of a foot is to reduce the freight capacity of the vessels by from 31 to 104 short tons. The weighted mean, based upon the percentages of the total yearly freight carried, is 75.6 short tons per tenth of a foot of draft, or 63 short tons per inch.

Of the 42 vessels in the 600-foot class, eight are of more than 8,000 tons register. Table 52 gives the dimensions of the three largest.

TABLE 52.—*Dimension of the 3 largest freight vessels on the Great Lakes.*

Name.	Length over all.	Beam.	Depth.	Regis- tered ton- nage.	Greatest cargo ever carried, short tons.	Short tons per tenth of foot of draft.
W. Grant Morden.....	625	59	32	8,974	13,721	17.3
Col. James M. Schoonmaker.....	617	64	33	8,603	15,148	113.2
Wm. P. Snyder, Jr.....	617	64	33	8,603	15,292	113.2

Photographs Nos. 172 to 183 illustrate the various types of ships used on the Great Lakes.

The amount of bulk freight shipped varies considerably from year to year. For use in these studies the mean of the four years ending in 1918 has been taken. The chief commodities included in this class are four—namely, iron ore, grain, limestone, and coal. The averages for the years mentioned were as in Table No. 53.

TABLE No. 53.—*Bulk freight carried in commerce on the Great Lakes.*

	Short tons.	Percent- age of total.
Iron ore, east to Lake Michigan.....	10,000,000	10.3
Iron ore, east to Lake Erie.....	45,000,000	46.4
Total iron ore.....	55,000,000	56.7
Grain, east from Lake Michigan.....	2,000,000	2.07
Grain, east from Lake Superior.....	4,000,000	4.13
Total grain.....	6,000,000	6.2
Stone, west to Lake Michigan.....	1,500,000	1.55
Stone, east to Lake Erie.....	4,500,000	4.65
Total stone.....	6,000,000	6.2
Coal, west to Lake Michigan.....	13,000,000	13.4
Coal, west to Lake Superior.....	17,000,000	17.5
Total coal.....	30,000,000	30.9
Grand total.....	97,000,000	100.0

Bulk freight rates are subject to considerable fluctuation, and were notably variable during war conditions in 1917-18. The rates are determined by governing bodies (during the war period by the United States Shipping Board) as "base rates" to and from "modern docks." "Slow docks" pay whatever is necessary above "base rates." "Slow docks" are those not only deficient in transfer facilities but also those comparatively difficult of access in inner harbors or where depth of water is lacking.

During the war freight rates, like everything else, arose to unprecedented heights, reaching a maximum in 1918. What the future rates will be is, of course, unknown, but it appears to be the general opinion that they will decline somewhat, although a return to prewar conditions is not to be expected. At the beginning of the 1919 season rates declined 10 or 15 per cent below the 1918 level. For the purpose of this study rates have been taken at 75 per cent of the values in 1918. Table No. 54 gives the rates prevailing in 1918. The column headed "Mean" contains the mean rate obtained by weighting each rate in proportion to the amount of traffic subject to it.

TABLE No. 54.—*Estimated Lake freight rates.*

Route.	Rate per short ton, 1918.	Weighted mean, 1918.	Adopted.	Revenue per 0.1-foot draft and 75.6 short tons.
Ore:				
To Lake Michigan.....	\$0.76	} \$0.86	\$0.65	\$49.14
To Lake Erie.....	.89			
Grain:				
From Lake Michigan.....	1.17	} 1.41	1.06	80.14
From Lake Superior.....	1.53			
Coal:				
To Lake Michigan.....	.58	} .52	.39	29.45
To Lake Superior.....	.48			
Stone:				
To Lake Michigan.....	.75	} .75	.56	42.34
To Lake Erie.....	.75			

Weighting each value in the last column by the per cent of the total freight movement which that commodity constitutes, the weighted mean value of the revenue lost through reduction of one-tenth of a foot in the available draft is found to be \$44.57 for each trip of a loaded vessel.

As the fleet of 530 vessels has a total capacity of 3,900,000 short tons per trip, the movement of the annual shipment of 97,000,000 tons requires 25 trips. A lowering of the lake level of one-tenth of a foot would cause an annual loss of revenue to vessel owners in 25 single trips of $530 \times 25 \times 44.57 = \$590,000$, and this loss would have to be made good by an increase in rates.

The normal schedule of lake freight vessels is to make 20 round trips per navigation season of about 240 days. This is not fully realized, due to delays caused by sea and fog, by repairs to machinery, and by accidents ranging from those requiring a few days for repairs to hull, to wrecking, and consequent withdrawal from the fleet.

As a matter of fact, while the normal freight movement could be accomplished by the whole fleet making 17 "going trips" with iron ore and grain and stone, and by 8 "return trips" with coal, it is really accomplished by some of the fleet, notably the larger vessels, making 20 or more round trips, and the others making a lesser number of trips, with frequent "return" trips without cargo. As the above figures are all based on weighted means, the correctness of the computation is not affected by these facts.

There is one circumstance that tends to reduce the above figure a trifle. When the load draft of a boat is reduced by one-tenth of a foot, there is, theoretically, a slight reduction in the coal consump-

tion required to drive the boat at its normal speed. The exact amount of this can not be determined, but it would seem that it must be very small indeed.

On the other hand, there are several items of loss to vessel owners or shippers that have not been considered. If the average vessel load is reduced 75.6 tons per trip, then in 25 trips the fleet will carry 1,000,000 tons less. In a busy season this might lead to extra trips after the official close of navigation when insurance is higher and accidents are more frequent. It might even lead to some of the freight being shipped by rail at a great advance in rates.

Further, there will be loss to the second-class shipping, the vessels drawing from 10 to 18 feet. Many of these trade into second-class ports where depths are much less than in the large ports, carrying the greatest cargo that the depth of water will allow. Any lowering of lake levels reduces their carrying capacity exactly as in the case of the bulk freighters.

Again, there will be some vessels which are just able to carry their full loads after the levels have been lowered, but nevertheless have an appreciably diminished clearance under their keels. This leads to losses through reduced speeds and creates greater probability of damage by stranding or collision.

These four items are all small. One is of a nature tending to reduce the figure of \$590,000 arrived at as the annual loss due to a one-tenth foot reduction in lake levels. The other three tend to increase it.

Nearly all the traffic of the St. Lawrence River is carried on by vessels loaded to the greatest draft which they can take through the locks of the Canadian canals. The available information about this traffic is not so extensive as in the case of the upper lake shipping, but there is sufficient data to form an estimate of the result of lake lowering.

The ships engaged in this trade are limited in size by the dimensions of the locks, which are 270 feet long from center to center of hollow quoins, 45 feet wide, and about 14 feet deep at ordinary low water. A typical vessel of this class is of 1,600 tons register; length, 250 feet over all; beam, 40 feet; molded depth, 19 feet; maximum cargo capacity, about 2,500 short tons. These vessels habitually load to the greatest draft which they can get over the sills of the locks. Any lowering of lake levels causes a corresponding reduction in load draft and cargo capacity. A lowering of one-tenth of a foot reduces the capacity by about 23 short tons.

As an example of the larger vessels built for the canal trade the steamer *R. L. Barnes* may be mentioned. She is 260 feet long over all, 43.2-foot beam, and 21.5-foot molded depth. Her registered tonnage is 1,914 tons and maximum cargo capacity 3,500 tons. The decreased capacity due to a reduction of one-tenth of a foot in draft is 26.4 tons.

During the war vessels of over 2,500 tons register were built on the Lakes and passed through the canals for use on the ocean. These vessels were not adapted to the lake trade and could not carry their full cargo through the locks, therefore they need not be considered further.

The average freight movement on the St. Lawrence canals is about 3,750,000 short tons per year. By far the greater part of this con-

sists, in about equal proportions, of coal from Lake Ontario and grain from Lake Superior. The small remainder is chiefly lumber and package freight. In 1917 and 1918 the rate for coal was \$1.50 per short ton. The grain rate was \$3.26 per short ton in 1917, and is understood to have been somewhat higher in 1918, although the exact figure is not at hand. For the years following the war the mean rate on these two commodities may reasonably be considered \$1.80 per short ton. Using this figure, the loss due to a lake lowering of one-tenth of a foot is $23 \times \$1.80 = \41.40 for each trip of a vessel.

The number of vessels in the fleet and their total capacity is not known nor is the number of loaded trips. The maximum cargoes carried are about 2,600 tons. It is probable that the average does not exceed 2,200 tons.

Adopting this figure, the loss due to one-tenth of a foot lowering of lake level is \$41.40 for each 2,200 short tons of freight moved, or about \$70,000 for the total freight moved per year. This is the loss to ships using the St. Lawrence canals caused by a lowering of one-tenth of a foot at any of the locks of those canals.

Table No. 47, Section G1, shows the total lowering of each lake caused by all the existing diversions. At mean stage the lowering is 0.47 foot on Lakes Michigan and Huron, 0.76 on Lake Erie, and 0.62 at Lock No. 25 on the St. Lawrence River. If the whole bulk freight traffic of the upper lakes entered Lake Erie the annual loss caused by the lowering would be $7.6 \times 590,000 = \$4,484,000$. As a matter of fact, only about 88 per cent of the total traffic uses this lake and the loss to it is $0.88 \times 4,484,000 = \$3,946,000$. The loss to the remaining 12 per cent on Lakes Michigan and Huron is $0.12 \times 4.7 \times 590,000 = \$333,000$. The loss to the traffic of the St. Lawrence canals is $6.2 \times 70,000 = \$434,000$. The total loss is the sum of those three amounts, or \$4,713,000 per year.

The lowering at Lock 25 of the St. Lawrence canals is greater than has been observed at any other point along that part of the St. Lawrence River bordering upon the United States, and this lowering has been used in the above computation. It is credibly reported that the lowering is greater in the purely Canadian portions of the river. If the lowering said to occur at Montreal is considered, the total loss will be increased from \$4,713,000 to \$4,758,000 per year.

Table No. 48, Section G3, shows the lowering that would be caused if all the diversions now contemplated should be added to those already existing. The amount is 0.76 foot for Lakes Michigan and Huron, 1.27 for Lake Erie, and 0.99 for Lock 25, St. Lawrence canals. Computing the amount of this loss in the same manner as above gives a total of \$7,825,000 per year. If the reported lowering at Montreal is adopted the amount is \$7,913,000 per year. Capitalized at 5 per cent this represents an investment loss of \$158,260,000.

It is of interest to compute separately the effect of the Chicago diversion. The present diversion of 8,800 cubic feet per second through the sanitary canal lowers Lakes Michigan and Huron 0.43 foot; Lake Erie, 0.41 foot; and Lock 25, 0.62 foot. The total loss to shipping is \$2,866,000 per year; this is \$326 per year for each cubic foot per second diverted or \$332 if the Montreal figure is used.

The power diversions at Niagara Falls, which are taken from the Chippawa-Grass Island pool, lower the upper lakes. An effective diversion of 23,000 cubic feet per second lowers Lakes Michigan and Huron 0.01 foot; Lake Erie, 0.10; and Lock No. 25, none. This amounts to a loss of \$526,000 per year, or \$23 per year for each cubic foot per second diverted.

In order that the magnitude and importance of the freight traffic of the Great Lakes may be better realized, table No. 55 has been prepared. This is a comparison of the total net register tonnage of ships entering and leaving the important ports of the world in the most recent year for which figures are at hand and also the total passing through the most important waterways. Figures for the Great Lakes are from the Chief of Engineer's Report for 1918, and the others are from the World Almanac for 1919.

TABLE NO. 55.—*Net registered tonnage entered and cleared from important ports or passing through important waterways in most recent year for which statistics are published.*

Port or waterway.	Year.	Net registered tonnage.	Port or waterway.	Year.	Net registered tonnage.
Detroit River ¹	1917	60,267,723	Kobe, Japan.....	1916	11,431,000
St. Marys River and canal ¹ ...	1917	65,307,233	Conneaut, Ohio ¹	1917	11,397,071
Duluth-Superior, Minnesota and Wisconsin ¹	1917	39,689,131	Genoa, Italy.....	1914	10,455,000
Hongkong-Victoria, China.....	1917	34,000,000	Naples, Italy.....	1914	10,153,000
Antwerp, Belgium.....	1912	27,479,000	Two Harbors, Minn. ¹	1917	10,019,643
Hamburg, Germany.....	1913	26,189,000	Montevideo, Uruguay.....	1917	10,000,000
New York, N. Y.....	1917	26,100,000	Colombo, Ceylon.....	1915	9,776,000
London, England.....	1914	23,459,000	Moji, Japan.....	1916	9,552,000
Liverpool, England.....	1914	22,772,000	Southampton, England.....	1914	9,307,000
Lisbon, Portugal.....	1914	18,543,000	Rio Janeiro, Brazil.....	1916	8,689,000
Buffalo, N. Y. ¹	1917	17,363,868	Marseilles, France.....	1916	8,701,000
Shanghai, China.....	1916	16,819,000	Rotterdam, Holland.....	1916	8,523,000
Cardiff, Wales.....	1914	16,223,000	Piraeus, Greece.....	1914	8,122,000
Ashtabula, Ohio ¹	1917	15,014,069	Havana, Cuba.....	1916	7,364,000
Cleveland, Ohio ¹	1917	15,080,058	Ashland, Wis. ¹	1917	7,147,348
Constantinople, Turkey.....	1913	14,319,000	Lorain, Ohio ¹	1917	7,029,832
Buenos Aires, Argentina.....	1912	14,247,000	Trieste, Austria.....	1913	6,926,000
Ports on Tyne River, Scotland.....	1914	13,241,000	Copenhagen, Denmark.....	1912	6,925,000
Singapore, Straits Settlements.....	1916	13,224,000	Milwaukee, Wis. ¹	1917	6,312,867
Toledo, Ohio ¹	1917	13,121,849	Yokohama, Japan.....	1916	6,300,000
Gibraltar, Gibraltar.....	1913	12,476,000	Cape Town, South Africa.....	1916	6,196,000
Suez Canal.....	1916	12,325,247	Panama Canal.....	1917	6,009,358

¹ Ports and waterways are on the Great Lakes.

From this it appears that the Detroit River is the most used waterway in the world, while the ship canals at the Sault are a close second. Either of these carries three and one-half times as much freight in the open season of about eight and one-half months as the Panama and Suez Canals together carry in a full year. Duluth leads the ports of the world by a decided margin, and 10 out of the 40 leading ports are on the Great Lakes. This is the more remarkable as all of the other ports are ice-free throughout the year, while the Great Lakes' commerce is almost completely stopped for nearly a third of each year.

It should be emphasized that the Great Lakes waterway is a national asset which benefits all parts of the country. The annual saving in freight rates due to the use of lake vessels in place of railroads exceeds a quarter of a billion dollars. The international supremacy of the United States in the iron and steel trade is based en-

tirely on this waterway. No part of the world produces iron ore in such quantities or so cheaply as the northern parts of Michigan, Wisconsin, and Minnesota. The great coal deposits of Pennsylvania and West Virginia offer unequaled supplies of fuel. The great advantage which these facts offer for the production of steel is handicapped by the great distance, nearly 1,000 miles, that separates the ore from the fuel. That, in spite of this handicap, the United States has become the greatest and cheapest producer of steel is due very largely to the fact that the development of the bulk freighter of the Great Lakes has linked the iron mines with the coal supply by a system of transportation whose cheapness is not even approached by that of any other route. Millions of tons of freight have been transported at rates as low as five-hundredths of a cent per ton-mile. Railroad rates on similar traffic have rarely been as low as three-tenths of a cent per ton-mile, which is six times the lake rate. The magnitude of this industry may be judged by the fact that the total shipment of ore in lake vessels since 1855 amounts to over three quarters of a billion long tons. The record year was 1916, in which over 64,000,000 long tons were carried. Since that year the yearly movement has not fallen below 60,000,000 long tons.

This is a condition from which the whole country benefits. The steel produced from this ore is used in every part of the United States and forms a part of almost every tool of our civilization from the needle to the locomotive. It is generally recognized that the volume of the steel trade is the best index of the prosperity of the country.

The grain and coal traffic of the Great Lakes is less in magnitude than the ore traffic, but is nevertheless of very great importance. The grain movement varies from 200,000,000 to over 400,000,000 bushels per annum. This grain, about 70 per cent of which is wheat, comes from the grain-raising States of the Middle West and Northwest and from the western Provinces of Canada. It forms a very important part of the food supply of the eastern and southeastern parts of the United States and the eastern parts of Canada, while a considerable proportion of it ultimately goes to Europe. The freight rates are extremely low, the prewar rate from Duluth to Buffalo being less than five-hundredths of a cent per ton-mile, while the rate for 1918 was only two-tenths of a cent per ton-mile. The Great Lakes thus form a very important factor in the distribution of the bread supply, their service being a benefit both to the western farmer and the eastern and southern consumer.

Of the coal production of the United States, more than two-thirds comes from West Virginia, Pennsylvania, Ohio, Indiana, and Illinois. Practically none is produced from the great region west of the Great Lakes and north of the Missouri River, and a large part of the fuel supply for these regions is shipped by way of the Great Lakes. Canada is also largely dependent upon the United States for coal, and there is a considerable movement of coal by water to Canadian ports on Lakes Superior, Erie, and Ontario, while over 1,000,000 tons per year are shipped to Montreal from American ports on Lake Ontario. About one-quarter of a million tons are shipped down the St. Lawrence for distribution to northern New York and New England. The total shipments of coal by lake average about 30,000,000 tons per annum.

Coal shipped from Lake Erie to Lake Superior gets a remarkably low rate, as it goes in vessels which would otherwise have to return in ballast for their next cargo of ore. In 1914 shipments from Buffalo, amounting to over 4,000,000 tons, paid an average rate of 0.0329 cent per ton-mile, which is probably a record for the cheap movement of freight. Even in 1918 the rate was only 0.0555 cent per ton-mile.

Coal is as necessary to modern industry as is steel, and in these northern latitudes it is as much a necessity of life as wheat. A very large part of the northern United States and more than half of Canada depends upon the lake trade for coal. This coal could not be carried by rail without a great increase in railroad equipment, and then only at a much higher rate. Anthracite coal delivered at Duluth by rail would probably cost \$3 or \$4 per ton more than if carried by water.

2. EFFECT UPON RIPARIAN INTERESTS.

The shore line of the Great Lakes and their connecting channels is more than 8,300 miles in length. Over the greater part of this distance the shore has the following characteristics: A sloping "beach" extends from some distance below the low-water mark to above ordinary high water. This beach may consist of sand, gravel, bowlders, or even of ledge rock. Behind it, in most places, is a sort of mound or barrier composed of material cast up by the greatest storms. If this material is sand it may be built up by the winds into dunes several hundred feet in height. Behind the mound the natural upland country is found, be it forest, arable land, or marsh.

A lowering or raising of the lake level along most of these shores has no effect whatever on the value of this land. It merely moves the water line a few feet up or down the beach, covering or uncovering a little of the valueless sand or gravel. If the level is lowered the landowner's holding of dry land is increased a trifle but he is none the richer thereby. No marketable grass or other crop will grow upon the barren strip thus exposed. He can build no permanent structure on it for, whether the stage be high or low, the greatest storms will hurl their destructive waves clear across the beach to the barrier in the rear. If the level is raised the owner loses a few square feet of land, but it is land which was of no value to him and he is none the poorer.

The above statements hold true over by far the greater part of the shore line of the Great Lakes, but there are places where changes in the level of the lakes are a matter of interest to the riparian owners. In places marshy lands adjoin the lakes or their tributaries, and the value is increased by low stages of the lakes. The land in the delta of the St. Clair River is a typical example. Here are many square miles of low, wet land on which grows a heavy crop of coarse, wild grasses. In wet seasons when Lake St. Clair is high these can not be harvested, but if the lake level is low the marsh dries out enough to carry the weight of men and horses and a considerable quantity of what is known as "marsh hay" is gathered. This is not suitable for stock feed but has a small market value, being used largely as a packing material.

Large areas of land such as this are found around Saginaw Bay on Lake Huron, and around Maumee Bay on Lake Erie. Some

is also found on the south shore of Lake Ontario and the east shore of Lake Michigan, and there is a very little on Lake Superior. Although this land amounts to a good many square miles, the increase of value at low stages amounts to very little, as the crop brings a very low price which barely pays for harvesting it and over much of this area marsh hay is not gathered at all.

Wherever land of this type is found there is usually a small area of land of a much more valuable nature. This is rich, black muck which can be used to raise celery and other valuable truck in seasons of low water, but is too wet for successful culture in other years. A low stage of water is a very valuable asset to the owner of land of this type. The total amount of such land is small. The most important examples are at Irondequoit Bay on Lake Ontario and in some of the harbors on the east shore of Lake Michigan.

Along the tributary and connecting rivers and the sheltered inlets of the Great Lakes the owner of the riparian lands is usually benefited by moderately high stages of water. In such places nearly every riparian owner has a boat of some sort, and small docks, boat houses, dredged slips, and similar structures are found in great abundance. These are usually built to suit the prevailing stages and lose a great deal of their value if the level falls to a lower stage. In summer-resort districts, such as the Thousand Islands and the St. Clair Flats, hundreds of such structures are to be found within a few miles. The advantage due to higher stages is not universal even in such instances; for in places like Buffalo, along Buffalo Creek, the damage from floods is increased and sites for houses are made less dry and desirable.

It has been the general experience of the War Department that years of abnormally high water cause but little comment, but that every season of unusually low stage brings a great number of complaints of damages done and requests for information as to the cause of these low levels and the possibilities of preventing them.

With the data at hand it is impossible to evaluate these effects in dollars and cents. It is believed they do not form a very large or important factor of the problem of lake levels.

3. VALUE TO CHICAGO OF ITS DIVERSION.

There are no impartial studies available of the question of the value to Chicago of its diversion.

The following statements are taken from the testimony presented by the sanitary district in the case of *United States v. Sanitary District of Chicago*. The expert witnesses from whose testimony this data is taken were men of eminence in their several professions and their testimony bears evidence of considerable study. It must be remembered, however, that these statements were entirely of an *ex parte* nature and intended to advance the cause of the sanitary district in the suit in which they were presented.

From an analysis of the typhoid-fever rate for the 13 years preceding the opening of the canal, and for the 13 years following, it was estimated that the people of the sanitary district were benefited to the amount of \$19,237,000 per year by the reduction of sickness

which the canal had effected. The average diversion during these years was 4,500 cubic feet per second. Hence the benefits received amounted to \$4,270 per annum for each cubic foot per second of diversion. This, however, is hardly a measure of the value of the diversion, as the reduction in disease could have been accomplished in some other manner.

If the privilege of diverting water were entirely taken away from the district, the work on the main canal, including the power house, would lose its value almost completely. The work on the Chicago River would retain part of its value.

The value of the intercepting sewers, pumping stations, etc., would not be much impaired. The following figures, quoted from the published record of the evidence, give approximately the amount of money which has been spent, all benefit of which would be lost if the diversion permit was stopped:

Right of way.....	\$9,700,000
Construction of main channels and controlling works.....	19,800,000
Joliet project.....	1,600,000
Interest, damages, general overhead (pro rata from total given in report).....	8,000,000
Calumet Sag project.....	14,300,000
Electrical development.....	5,300,000
Total.....	58,700,000

If the diversion of water were forbidden this amount of expenditure would become useless. Reduced to annual charges on a 4½ per cent interest rate, this amounts practically to \$2,500,000.

In addition the sanitary district would lose the 21,000 horsepower now generated at Lockport and the 3,350 horsepower generated at Joliet. This power would thereafter have to be generated by steam. The increased cost might well be \$20 per horsepower per year, or about \$500,000 per year.

This makes the total loss due to the cutting off of the present diversion \$3,000,000 per year. To this must be added the cost of so purifying the sewage of the district that it can safely be discharged into the lake and of filtering the water supply of the whole district. None of the witnesses testified directly on this matter, but their testimony furnishes a basis for a rough estimate.

One witness outlined a plan for the treatment of the sewage of 1,200,000 people residing in the Calumet division of the district so that it would be fit to be discharged into Lake Michigan. His estimate of the construction cost was \$9,257,500 and of the annual cost of operation \$419,000. If interest on the cost of construction is assumed at 4½ per cent, and depreciation at 2 per cent, the total annual cost will be \$997,000, or \$0.83 per capita. As the population of the sanitary district is 2,764,000, the cost of sewage treatment at the same rate would be \$2,300,000 per year.

Another witness testified that the cost of proper water filtration works with a capacity of 520,000,000 gallons per day would be \$13,000,000, and the cost of operation \$500,000 per year. Using the same allowances as above, this would give an annual cost of \$2,530 per million gallons per day. For the present consumption of about 680,000,000 gallons per day the annual cost would be about \$1,700,000.

Combining these items we get the following figures for the annual loss which Chicago would suffer by being deprived of the use of lake water through the sanitary canal:

Interest on, abandoned investment.....	\$2,500,000
Loss by change from electric power to steam.....	500,000
Cost of sewage treatment.....	2,300,000
Cost of water filtration.....	1,700,000
Total	7,000,000

As the present diversion averages about 8,800 cubic feet per second, the value of each cubic foot per second may be taken as about \$800 per year.

The sanitary district has a permit from the Secretary of War authorizing it to divert 4,167 cubic feet per second down the canal. The State law under which it operates requires it to dilute the untreated sewage at the rate of $3\frac{1}{2}$ cubic feet per second for each 1,000 of tributary population. Most sanitary engineers agree that this is a reasonable requirement. Under this law the required diversion for the present population would be about 8,500 cubic feet per second. If the limits of the permit were strictly enforced the sanitary district would probably find it best to treat its sewage in such a manner that the dilution effected by 4,167 cubic feet per second would be sufficient. Preliminary estimates of the cost of such a procedure have been made by the engineers of the district and are published in the record of the testimony of the case of *United States v. Sanitary District of Chicago*. Table No. 56 is based upon this testimony.

TABLE NO. 56.—*Estimate of value to Chicago of its diversion.*

Item.	Population to be served.		
	3,000,000	3,600,000	4,200,000
Dilution required by State law, cubic feet per second.....	10,000	12,000	14,000
Cost of disposal by legal dilution, capitalized at $4\frac{1}{2}$ per cent....	\$62,825,600	\$77,720,070	\$90,213,900
Cost if treated and diluted by 4,167 cubic feet per second.....	\$259,577,871	\$296,208,700	\$333,026,400
Difference in capitalized cost.....	\$196,752,271	\$218,487,370	\$252,812,500
Difference per year.....	\$8,360,000	\$9,280,000	\$10,740,000
Difference per cubic foot per second per year.....	\$836	\$773	\$768

It will be observed that these figures for the yearly value of a diversion of 1 cubic foot per second are fairly comparable to the value of \$800 derived from somewhat different premises.

These values can not be given too great confidence. The evidence on which they are based was presented with the desire to prove that the value of the diversion was very great. The ex parte nature of this data should be kept in mind. On the other hand, it must be remembered that these costs are based on the prices of materials and labor as they existed seven or eight years ago, since which time the cost of many of the items involved has more than doubled.

4. VALUE TO PUBLIC OF EFFECT ON POWER PRODUCTION.

In Section F of this report it has been shown that the diversion of 20,000 cubic feet per second from the Niagara River on the American side as authorized by the present treaty is sufficient to operate a power development with a capacity of nearly 600,000 horsepower. The value of this diversion to the public is the difference between the

selling price of this power and the selling price of the same power if it were developed in a steam plant without the diversion of any water. An attempt to estimate this value will now be made.

The three best plans for using this diversion are those which have been entitled the "canal project," the "pressure-tunnel project," and the "compound two-stage project." The power output and costs of these three do not vary greatly and accordingly the mean of the figures given for these three projects in Section F-10 will be used. The construction costs given in Section F-10 do not include "development expense" or "original overhead expense," accordingly this cost has been increased 10 per cent to cover these items. The assumption that the growth of the electrochemical industries would bring the load factor up to 90 per cent has been made as in Section F-10. The costs of producing power given in that section did not include any profit to the company. The selling price of power will be fixed by some regulative commission and will certainly allow such a profit. The amount of 3 per cent of the cost of the plant has therefore been added to cover this item.

For computing the cost of developing this amount of power by steam, detailed costs were obtained from two of the largest companies in the Great Lakes district which generate electricity in this manner. The means of the various items given by the two companies was adopted except that the fixed charges were increased by 60 per cent because it was estimated that the cost of building a plant to-day would be that much more than the cost of building the plants considered.

Table No. 57 gives a comparison of the cost of steam-electric power with Niagara power.

TABLE No. 57.—Comparative costs of steam and hydraulic power at Niagara Falls, N. Y.

Item.	Cost per horsepower year.	
	Steam-electric.	Niagara.
Coal—6 tons, at \$4.50.....	\$27. 00	.....
Other operation and maintenance expense.....	8. 20	\$1. 90
Fixed charges (10 per cent on Niagara power, 13 per cent for steam-electric).....	12. 60	14. 50
Profit, 3 per cent of construction cost.....	2. 90	3. 10
Selling price of power.....	50. 70	19. 50
Selling price reduced to cents per kilowatt hour.....	. 78	. 30

These are prices for very large amounts of untransformed power sold at the power-house switchboard at generator voltage with a load factor of 90 per cent. The cost of transformation, transmission and distribution, as well as advertising and selling costs, must be added to these figures to get the price actually to be paid by the consumer. These will vary from a few tenths of a cent to 10 or 15 cents per kilowatt hour, depending upon the nature of the customer's demand, but there is no reason why these items should not be substantially equal for steam or hydraulic power. The comparison can therefore be made directly from the figures in this table.

The saving due to the use of Niagara power instead of steam is \$31.20 per horsepower year. The diversion of 20,000 cubic feet per second produces 526,000 horsepower (mean of the three projects). Then the total saving is \$16,410,000 per year, or \$820 per cubic foot per second per year.

This is the value that the American diversion at Niagara would have if the full treaty amount of 20,000 cubic feet per second were used in the manner proposed in Section F. The value of the present diversion as now used is, of course, somewhat less. In spite of the fact that the efficiency of the present plants is less than that of the plants proposed, the cost of producing power is also less. This is because the present plants develop only the easiest and cheapest part of the total head, and because they were built very much more cheaply than present prices would permit. It is estimated that the selling price corresponding to those given above would be about \$13 per horsepower year. The saving over the use of steam power would then be \$37.70 per horsepower year. The present diversion is about 17,560 cubic feet per second. This produces about 247,000 horsepower. Hence the saving is \$9,310,000 per year, or \$530 per cubic foot per second per year.

Data for the Canadian plants is not available, but it is believed that no great error will be introduced if \$500 is adopted as the average for all the plants at Niagara. As the total diversion is about 50,886 cubic feet per second, the total saving due to the diversion of water at Niagara is, in round numbers, \$25,000,000 per year.

These figures represent the actual saving in money effected. There are other intangible benefits received by the public. One of these is the saving in coal. It is well known that the available supply of coal is limited and must ultimately be exhausted. Also at present the capacity of the coal mining and distributing system is scarcely sufficient to supply the demand for this fuel. A year and a half ago it proved for a time quite insufficient. If the power used at Niagara were produced from coal the annual consumption would be increased by nearly four million tons, which would cause an appreciable increase in the rate of exhaustion of the coal supply, and in the difficulties of mining and distributing the annual output of the mines.

If the Niagara diversion were cut off the building of steam stations could replace the power, but only at a much higher price. The money loss would not be the only one. The public has been greatly benefited by the cheapness of Niagara power as well as by its quantity. The low price at which this power is available has stimulated the electro-chemical industries and made possible the development of new products. Many of the products made at the Falls would not be produced at all if power were not to be had at this very low price. These products proved invaluable during the war.

At Massena, Lockport, Ill., and other places where the water of the Great Lakes is diverted for power development the saving in money and in intangible items is similar in nature, but less in amount than at Niagara Falls. The data for an estimate are not at hand. It has been stated that the value of the water used for power by the Sanitary District of Chicago at Lockport is \$70 per cubic foot per second per year. The weight to be given to this estimate is not known.

W. S. RICHMOND.

APPENDIX G.

INTERNATIONAL AND INTERSTATE MATTERS INVOLVED.

[Section I of Mr. Richmond's report.]

I. INTERNATIONAL MATTERS INVOLVED.

Historical.—Previous to the appointment of the International Waterways Commission there was no international supervision of the use of the waters of the Great Lakes. In each country such works were built and such water diverted as was desired. Most of these uses were small, and no serious objections were raised, the effects on the other country being trifling in each case. The building of the Canadian canals in the St. Lawrence River caused decided changes along that stream, but at the time American interests on the river were very small and no protest was made. In the same way the development of waterpower at Waddington and Massina attracted little attention in Canada. The building of the north cut at the head of the Galop Canal aroused considerable talk on both sides of the Lake Ontario through fear that it would cause serious lowering of that lake. Later the building of the Gut Dam required the permission of the United States because part of it was located on this side of the boundary. None of these events led to the institution of any permanent policy of control of international waters.

The same is true of the early small power developments at Niagara and on the Welland Canal, and of the building and enlarging of the Welland and Erie Canals and of the ship canals on the St. Marys River. In all of these cases the damage done across the boundary line was small and usually unnoticed.

Between 1890 and 1905 this state of affairs was radically altered. The construction of the Chicago Drainage Canal, and of the large power developments at Sault Ste. Marie and at Niagara Falls, aroused public interest in the use of lake waters, while the occurrence of unusually low lake stages in the early nineties alarmed the shipping interests. Studies of the relation between diversions and lake lowering were undertaken by the Government. The agitation led to the appointment of the International Waterways Commission in 1902, and resulted ultimately in the negotiation of the treaty of 1910 and the appointment of the International Joint Commission.

General principles of control of diversions.—In the joint report of the International Waterways Commission, dated May 3, 1906, six general principles were laid down as "applicable to all diversions or uses of waters adjacent to the international boundary, and of all streams which flow across the boundary." Principles Nos. 4 and 5 apply only to streams crossing the boundary and have no bearing on questions relating to the Great Lakes. The other four form so good a state-

ment of the proper principles governing the use of the waters of the Lakes that they are here reproduced:

1. In all navigable waters the use for navigation purposes is of primary and paramount right. The Great Lakes system on the boundary between the United States and Canada, and finding its outlet by the St. Lawrence to the sea, should be maintained in its integrity.

2. Permanent or complete diversions of navigable waters or their tributary streams should only be permitted for domestic purposes and for the use of locks in navigation canals.

3. Diversions can be permitted of a temporary character, where the water is taken and returned, when such diversions do not interfere in any way with the interests of navigation. In such cases each country is to have a right to diversion in equal quantities.

* * * * *

6. A permanent joint commission can deal much more satisfactorily with the settlement of all disputes arising as to the application of these principles, and should be appointed.

In the above the term "permanent diversions" is understood to mean diversions of water from the Great Lakes system to some other watershed (e. g., the diversion at Chicago), while "diversions of a temporary character" is taken to mean diversions of water which is returned to the Great Lakes system (e. g., the diversions at Niagara Falls). The term "domestic purposes" is understood to cover all ordinary sanitary uses.

One more principle is needed to make a complete system for dealing with diversions from the Great Lakes. This might be worded thus: "Diversions of water from tributaries of the Great Lakes, unless the water is returned to the same tributary, shall be considered as diversions from the Lakes."

About principle 1 there has been no real dispute. Even where the value of a stream as a water power is much greater than its value as a highway it has been recognized that the paramount right is that of navigation and that water power developments must be so made as not to hinder navigation.

Principle 2 declares that each country can take what water it needs for sanitary and navigation purposes. As a usual thing the quantity required for such uses is comparatively small and the effect of the diversion upon lake levels is nearly or quite negligible. In case the diversion is large, as at Chicago, the proper compensating works should be provided. The most important diversions now made for sanitary or navigation purposes are those of the Chicago Sanitary Canal, the Welland Canal, and the New York State Barge Canal. The Erie and Ontario Sanitary Canal is a proposed instance of this type, and the time may come when similar diversions by the Canadian towns on the south shore of the Niagara Peninsula may deserve consideration.

The validity of principle 3 has been substantially recognized in the settlement of the question of power diversion at Sault Ste. Marie. When the matter of large scale development of the water power of the St. Lawrence River is taken up, this principle will no doubt be applied there.

The present treaty with Great Britain does not apply this principle to diversions from the upper Niagara River, but allows a diversion of 36,000 cubic feet per second in Canada and only 20,000 cubic

feet per second in the United States. The reason for this inequality becomes fully apparent upon study of the report of the American members of the International Waterways Commission, dated March 19, 1906. This report formed the ground work for the Niagara provisions of the treaty. The amount to be diverted on the Canadian side was fixed at 36,000 cubic feet per second with a view to allowing the companies on that side the amounts of water for which they then had works under construction. Similarly the amount allowed on the American side was limited to 20,000. The inequality of the diversion was recognized, but it was considered better to preserve the Falls by keeping the total quantity as low as possible without causing losses to investors, than to preserve the equality of diversions at the expense of the Falls. The International Waterways Commission, in commenting on this matter, said:

The advantage is more apparent than real, since the power generated on the Canadian side will, to a large extent, be transmitted to and used in the United States. In the negotiation of a treaty, however, the point should be considered.

When the treaty came to be negotiated, however, this matter was not included. The quantity of electric energy transmitted into the United States has been reduced from time to time as the market for power was built up in Canada, and it now appears to be a matter of comparatively few years before all such importation will be cut off. In this connection the commission classed the Chicago diversion and a portion of the Welland diversion with the Niagara diversions. The treaty did not thus group these, but treated the Niagara River above the Falls as a separate entity.

Diversions for sanitary purposes, like that at Chicago, were not limited nor were existing diversions, such as this sanitary diversion at Chicago or the power diversion of the Welland Canal, as existing at the time of the ratification of the treaty—to be considered when making further equal divisions of diversions. It is also to be noted that the diversions at Niagara, which were recommended to protect investors, were all planned to be returned to the river at the Maid of the Mist Pool, just below the Falls. In the treaty, however, the point of return was not limited. Canada thus gained a further advantage over the United States, apparently not contemplated by the International Waterways Commission, of 16,000 cubic feet per second over the 90-foot head of the Whirlpool and Lower Rapids.

If the remedial works, described in Appendix C of this report, are built the situation will be completely altered, and there will no longer be any reason for an unequal division of diversions for power. Principle 3 should then be applied and the water divided equally between the two countries.

The only place where the application of principle 3 leads to serious difficulty is in the Niagara Peninsula. Here more than 3,000 cubic feet per second is diverted down the Welland Canal for use in developing power. It has also been proposed to divert water through the Grand River, across the divide, to some point on Lake Ontario, near Hamilton. While a diversion of the same nature from Lake Erie to Lake Ontario on the American side is possible, and has been urged by certain parties, it is not an economically desirable scheme. The objections to it have been treated in Section C-8 of this report.

An equal division of the diversion here would give the United States rights which it could not properly use.

It should be remembered that a diversion from Lake Erie to Lake Ontario will not develop quite as much power as an equal diversion from the upper to the lower Niagara River, because of the larger losses in canals and tunnels. Furthermore, the adverse effect upon navigation of the diversion from Lake Erie is much the greater. For this reason it is believed that power diversion from Lake Erie should be limited strictly to that now existing and that the Grand River and the Erie and Ontario Sanitary Canal schemes should not be permitted. This will leave to Canada a small advantage over the strictly equal division called for by principle 3, but it is felt that this is better than to encourage further diversions of this character or, on the other hand, to attempt to shut off long-existing diversions where much capital has been invested.

Principle 6 has been accepted by both countries, and the International Joint Commission has been in existence for several years.

The principle that diversions from tributaries are to be considered diversions from the lakes is needed in the interest of clearness. This has always been accepted in the case of the diversions at Chicago. Both the Federal Government and the sanitary district speak of the flow measured at Lockport as being the diversion from Lake Michigan. As a matter of fact, the flow so measured, is partly diverted from Lake Michigan and partly from the various branches of the Chicago River—tributaries of the lake. The effect upon lake levels of a diversion from the river is exactly the same as the effect of a diversion from the lake. In this case the diversion from the lake itself is a diversion from a tributary of the boundary waters for the waters of Lake Michigan are not held to be boundary waters.

The same condition exists in the diversion of the New York State Barge Canal, where the diversion is taken partly from the Niagara River and partly from Tonawanda and Ellicott Creeks. Here the Niagara River is a boundary stream, and Tonawanda and Ellicott Creeks are tributaries. The works now being built to divert water from the Calumet River and from Chippawa Creek will bring about similar conditions as would also the proposed diversion of water from the Grand River. In all these cases it is believed that the adoption of the new principle would simplify rather than complicate the control and regulation of these diversions, whether by the Joint Commission or by the Federal, State, or Provisional Governments.

Lake levels.—Anything affecting lake levels is obviously an international affair, for in no case can the levels of one of the Lakes be lowered without affecting both countries. This is true even of Lake Michigan, whose waters are not boundary waters, but which unites with Lake Huron to form what is hydraulically one lake. The diversion of water by the Sanitary District of Chicago has decreased the available draft of the Canadian ship canals and locks on the St. Lawrence River. The diversion of the Ontario Power Co. has reduced the navigable depth of the channels approaching the American ports of Tonawanda and Niagara Falls. Many other instances could be adduced where diversions made in one country have inflicted damage upon the other country.

Compensating works.—The construction and maintenance of compensating works is another matter which requires international action. In almost any case where works on a large scale are to be built the works themselves will lie on both sides of the boundary. The undesirable conditions which they are intended to correct exist on both sides of the boundary. Many parts of the Great Lakes system have been lowered by a number of different diversions, some made in the United States and some in Canada. It might be possible to compensate separately with works in each country for each separate effect, but it will be far more economical and satisfactory if as few structures as practicable be used, and if these are constructed jointly by the two Nations. The expense involved in these works would equitably be apportioned between them according to the extent of the lowering caused by each party.

Preservation of Niagara Falls.—Another matter which is entirely of an international character is the preservation of the scenic beauty of Niagara Falls. This is a matter of equal interest to the citizens of both countries. The remedial works described in Appendix C lie on both sides of the boundary, and international cooperation is necessary for their construction. If the plan outlined in Appendix C of increasing the diversion around the Falls to 40,000 cubic feet per second on each side and building a remedial weir is adopted, it is believed that the cost should be equally divided between the two Nations. Further discussion of this matter is found in Appendix C.

2. TREATY PROVISIONS.

The present treaty.—In its report of May 3, 1906, the International Waterways Commission recommended that a treaty be negotiated between the United States and Great Britain, limiting the diversion of water at Niagara Falls. On June 29, 1906, the Burton Act was approved. Section 4 of this act requested the President to open negotiations with Great Britain for obtaining such a treaty. After some delay the treaty was prepared, and it was signed at Washington January 11, 1909. Having been duly ratified on May 5, 1910, it was proclaimed by the President on May 13 of the same year.

The text of the treaty is as follows:

Treaty Series, No. 548. Treaty Between the United States and Great Britain.—Boundary waters between the United States and Canada.

Signed at Washington January 11, 1909.

Ratification advised by the Senate March 3, 1909.

Ratified by the President April 1, 1910.

Ratified by Great Britain March 31, 1910.

Ratifications exchanged at Washington May 5, 1910.

Proclaimed May 13, 1910.

BY THE PRESIDENT OF THE UNITED STATES OF AMERICA.

A PROCLAMATION.

Whereas a treaty between the United States of America and His Majesty the King of the United Kingdom of Great Britain and Ireland and of the British dominions beyond the seas, Emperor of India, to prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the

rights, obligations, or interests of either in relation to the other, or to inhabitants of the other along their common frontier, and to make provision for the adjustment and settlement of all such questions as may hereafter arise, was concluded and signed by their respective plenipotentiaries at Washington on the eleventh day of January, one thousand nine hundred and nine, the original of which treaty is, word for word, as follows:

The United States of America and His Majesty the King of the United Kingdom of Great Britain and Ireland and of the British dominions beyond the seas. Emperor of India, being equally desirous to prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the rights, obligations, or interests of either in relation to the other or to the inhabitants of the other along their common frontier, and to make provision for the adjustment and settlement of all such questions as may hereafter arise, have resolved to conclude a treaty in furtherance of these ends, and for that purpose have appointed as their respective plenipotentiaries:

The President of the United States of America, Elihu Root, Secretary of State of the United States; and

His Britannic Majesty, the Right Honorable James Bryce, O. M., his ambassador extraordinary and plenipotentiary at Washington.

Who, after having communicated to one another their full powers, found in good and due form, have agreed upon the following articles:

PRELIMINARY ARTICLES.

For the purposes of this treaty boundary waters are defined as the waters from main shore to main shore of the lakes and rivers and connecting waterways or the portions thereof, along which the international boundary between the United States and the Dominion of Canada passes, including all bays, arms, and inlets thereof, but not including tributary waters which in their natural channels would flow into such lakes, rivers, and waterways, or waters flowing from such lakes, rivers, and waterways, or the waters of rivers flowing across the boundary.

ARTICLE I.

The High Contracting Parties agree that the navigation of all navigable boundary waters shall forever continue free and open for the purposes of commerce to the inhabitants and to the ships, vessels, and boats of both countries equally, subject, however, to any laws and regulations of either country, within its own territory, not inconsistent with such privilege of free navigation and applying equally and without discrimination to the inhabitants, ships, vessels, and boats of both countries.

It is further agreed that so long as this treaty shall remain in force this same right of navigation shall extend to the waters of Lake Michigan and to all canals connecting boundary waters and now existing or which may hereafter be constructed on either side of the line. Either of the High Contracting Parties may adopt rules and regulations governing the use of such canals within its own territory and may charge tolls for the use thereof, but all such rules and regulations and all tolls charged shall apply alike to the subjects or citizens of the High Contracting Parties and the ships, vessels, and boats of both of the High Contracting Parties, and they shall be placed on terms of equality in the use thereof.

ARTICLE II.

Each of the High Contracting Parties reserves to itself or to the several State governments on the one side and the Dominion or Provincial Governments on the other, as the case may be, subject to any treaty provisions now existing with respect thereto, the exclusive jurisdiction and control over the use and diversion, whether temporary or permanent, of all waters on its own side of the line which in their natural channels would flow across the boundary or into boundary waters; but it is agreed that any interference with or diversion from their natural channel of such waters on either side of the boundary, resulting in any injury on the other side of the boundary, shall give rise to the same rights and entitle the injured parties to the same legal remedies as if such injury took place in the country where such diversion or interference

occurs; but this provision shall not apply to cases already existing or to cases expressly covered by special agreement between the Parties hereto.

It is understood, however, that neither of the High Contracting Parties intends by the foregoing provision to surrender any right which it may have to object to any interference with or diversion of waters on the other side of the boundary, the effect of which would be productive of material injury to the navigation interests on its own side of the boundary.

ARTICLE III.

It is agreed that, in addition to the uses, obstructions, and diversions heretofore permitted or hereafter provided for by special agreement between the Parties hereto, no further or other uses or obstructions or diversions, whether temporary or permanent, of boundary waters on either side of the line, affecting the natural level or flow of boundary waters on the other side of the line, shall be made except by authority of the United States or the Dominion of Canada within their respective jurisdiction and with the approval, as hereinafter provided, of a joint commission, to be known as the International Joint Commission.

The foregoing provisions are not intended to limit or interfere with the existing rights of the Government of the United States on the one side and the Government of the Dominion of Canada on the other, to undertake and carry on governmental works in boundary waters for the deepening of channels, the construction of breakwaters, the improvement of harbors, and other governmental works for the benefit of commerce and navigation, provided that such works are wholly on its own side of the line and do not materially affect the level or flow of the boundary waters on the other, nor are such provisions intended to interfere with the ordinary use of such waters for domestic and sanitary purposes.

ARTICLE IV.

The High Contracting Parties agree that, except in cases provided for by special agreement between them, they will not permit the construction or maintenance on their respective sides of the boundary of any remedial or protective works or any dams or other obstructions in waters flowing from boundary waters or in waters at a lower level than the boundary in rivers flowing across the boundary, the effect of which is to raise the natural level of waters on the other side of the boundary unless the construction or maintenance thereof is approved by the aforesaid International Joint Commission.

It is further agreed that the waters herein defined as boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other.

ARTICLE V.

The High Contracting Parties agree that it is expedient to limit the diversion of waters from the Niagara River so that the level of Lake Erie and the flow of the stream shall not be appreciably affected. It is the desire of both Parties to accomplish this object with the least possible injury to investments which have already been made in the construction of power plants on the United States side of the river under grants of authority from the State of New York, and on the Canadian side of the river under licenses authorized by the Dominion of Canada and the Province of Ontario.

So long as this treaty shall remain in force no diversion of the waters of the Niagara River above the Falls from the natural course and stream thereof shall be permitted except for the purposes and to the extent hereinafter provided.

The United States may authorize and permit the diversion within the State of New York of the waters of said river above the Falls of Niagara, for power purposes, not exceeding in the aggregate a daily diversion at the rate of twenty thousand cubic feet of water per second.

The United Kingdom, by the Dominion of Canada, or the Province of Ontario, may authorize and permit the diversion within the Province of Ontario of the waters of said river above the Falls of Niagara, for power purposes, not exceeding in the aggregate a daily diversion at the rate of thirty-six thousand cubic feet of water per second.

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The prohibitions of this article shall not apply to the diversion of water for sanitary or domestic purposes, or for the service of canals for the purposes of navigation.

ARTICLE VI.

The High Contracting Parties agree that the Saint Mary and Milk Rivers and their tributaries (in the State of Montana and the Provinces of Alberta and Saskatchewan) are to be treated as one stream for the purposes of irrigation and power, and the waters thereof shall be apportioned equally between the two countries, but in making such equal apportionment, more than half may be taken from one river and less than half from the other by either country so as to afford a more beneficial use to each. It is further agreed that in the division of such waters during the irrigation season, between the 1st of April and 31st of October, inclusive, annually, the United States is entitled to a prior appropriation of five hundred cubic feet per second of the waters of the Milk River, or so much of such amount as constitutes three-fourths of its natural flow, and that Canada is entitled to a prior appropriation of five hundred cubic feet per second of the flow of Saint Mary River, or so much of such amount as constitutes three-fourths of its natural flow.

The channel of the Milk River in Canada may be used at the convenience of the United States for the conveyance, while passing through Canadian territory, of waters diverted from the Saint Mary River. The provisions of Article II of this treaty shall apply to any injury resulting to property in Canada from the conveyance of such waters through the Milk River.

The measurement and apportionment of the water to be used by each country shall from time to time be made jointly by the properly constituted reclamation officers of the United States and the properly constituted irrigation officers of His Majesty under the direction of the International Joint Commission.

ARTICLE VII.

The High Contracting Parties agree to establish and maintain an International Joint Commission of the United States and Canada, composed of six commissioners, three on the part of the United States appointed by the President thereof, and three on the part of the United Kingdom appointed by His Majesty on the recommendation of the Governor in Council of the Dominion of Canada.

ARTICLE VIII.

This International Joint Commission shall have jurisdiction over and shall pass upon all cases involving the use or obstruction or diversion of the waters with respect to which, under Articles III and IV of this treaty, the approval of this commission is required, and in passing upon such cases the commission shall be governed by the following rules or principles which are adopted by the High Contracting Parties for this purpose:

The High Contracting Parties shall have, each on its own side of the boundary, equal and similar rights in the use of the waters hereinbefore defined as boundary waters.

The following order of precedence shall be observed among the various uses enumerated hereinafter for these waters, and no use shall be permitted which tends materially to conflict with or restrain any other use which is given preference over it in this order of precedence:

First. Uses for domestic and sanitary purposes.

Second. Uses for navigation, including the service of canals for the purposes of navigation.

Third. Uses for power and for irrigation purposes.

The foregoing provisions shall not apply to or disturb any existing uses of boundary waters on either side of the boundary.

The requirement for an equal division may, in the discretion of the commission, be suspended in cases of temporary diversions along boundary waters at points where such equal division can not be made advantageously on account of local conditions and where such diversion does not diminish elsewhere the amount available for use on the other side.

The commission in its discretion may make its approval in any case conditional upon the construction of remedial or protective works to compensate so far

as possible for the particular use or diversion proposed, and in such cases may require that suitable and adequate provision, approved by the commission, be made for the protection and indemnity against injury of any interests on either side of the boundary.

In cases involving the elevation of the natural level of waters on either side of the line as a result of the construction or maintenance on the other side of remedial or protective works or dams or other obstructions in boundary waters or in waters flowing therefrom or in waters below the boundary in rivers flowing across the boundary, the commission shall require, as a condition of its approval thereof, that suitable and adequate provision, approved by it, be made for the protection and indemnity of all interests on the other side of the line which may be injured thereby.

The majority of the commissioners shall have power to render a decision. In case the commission is evenly divided upon any question or matter presented to it for decision, separate reports shall be made by the commissioners on each side to their own Government. The High Contracting Parties shall thereupon endeavor to agree upon an adjustment of the question or matter of difference, and if an agreement is reached between them it shall be reduced to writing in the form of a protocol, and shall be communicated to the commissioners, who shall take such further proceedings as may be necessary to carry out such agreement.

ARTICLE IX.

The High Contracting Parties further agree that any other questions or matters of difference arising between them involving the rights, obligations, or interests of either in relation to the other or to the inhabitants of the other, along the common frontier between the United States and the Dominion of Canada, shall be referred from time to time to the International Joint Commission for examination and report, whenever either the Government of the United States or the Government of the Dominion of Canada shall request that such questions or matters of difference be so referred.

The International Joint Commission is authorized in each case so referred to examine into and report upon the facts and circumstances of the particular questions and matters referred, together with such conclusions and recommendations as may be appropriate, subject, however, to any restrictions or exceptions which may be imposed with respect thereto by the terms of the reference.

Such reports of the commissions shall not be regarded as decisions of the questions or matters so submitted either on the facts or the law, and shall in no way have the character of an arbitral award.

The commission shall make a joint report to both Governments in all cases in which all or a majority of the commissioners agree, and in case of disagreement the minority may make a joint report to both Governments or separate reports to their respective Governments.

In case the commission is evenly divided upon any question or matter referred to it for report, separate reports shall be made by the commissioners on each side to their own Government.

ARTICLE X.

Any questions or matters of difference arising between the High Contracting Parties involving the rights, obligations, or interests of the United States or of the Dominion of Canada either in relation to each other or to their respective inhabitants, may be referred for decision to the International Joint Commission by the consent of the two parties, it being understood that on the part of the United States any such action will be by and with the advice and consent of the Senate, and on the part of His Majesty's Government with the consent of the Governor General in Council. In each case so referred the said commission is authorized to examine into and report upon the facts and circumstances of the particular questions and matters referred, together with such conclusions and recommendations as may be appropriate, subject, however, to any restrictions or exceptions which may be imposed with respect thereto by the terms of the reference.

A majority of the said commission shall have power to render a decision or finding upon any of the questions or matters so referred.

If the said commission is equally divided or otherwise unable to render a decision or finding as to any questions or matters so referred, it shall be the duty of the commissioners to make a joint report to both Governments, or separate reports to their respective Governments, showing the different conclusions

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arrived at with regard to the matters or questions so referred, which questions or matters shall thereupon be referred for decision by the High Contracting Parties to an umpire chosen in accordance with the procedure prescribed in the fourth, fifth, and sixth paragraphs of Article XLV of The Hague Convention for the pacific settlement of international disputes, dated October eighteenth, nineteen hundred and seven. Such umpire shall have power to render a final decision with respect to those matters and questions so referred on which the commission failed.

ARTICLE XI.

A duplicate original of all decisions rendered and joint reports made by the commission shall be transmitted to and filed with the Secretary of State of the United States and the Governor General of the Dominion of Canada, and to them shall be addressed all communications of the commissions.

ARTICLE XII.

The International Joint Commission shall meet and organize at Washington promptly after the members thereof are appointed, and when organized the commission may fix such times and places for its meetings as may be necessary, subject at all times to special call or direction by the two Governments. Each commissioner, upon the first joint meeting of the commission after his appointment, shall, before proceeding with the work of the commission, make and subscribe a solemn declaration in writing that he will faithfully and impartially perform the duties imposed upon him under this treaty, and such declaration shall be entered on the records of the proceedings of the commission.

The United States and Canadian sections of the commission may each appoint a secretary, and these shall act as joint secretaries of the commission at its joint session, and the commission may employ engineers and clerical assistants from time to time as it may deem advisable. The salaries and personal expenses of the commission and of the secretaries shall be paid by their respective Governments, and all reasonable and necessary joint expenses of the commission incurred by it shall be paid in equal moieties by the High Contracting Parties.

The commission shall have power to administer oaths to witnesses, and to take evidence on oath whenever deemed necessary in any proceeding, or inquiry, or matter within its jurisdiction under this treaty, and all parties interested therein shall be given convenient opportunity to be heard, and the High Contracting Parties agree to adopt such legislation as may be appropriate and necessary to give the commission the powers above mentioned on each side of the boundary, and to provide for the issue of subpoenas and for compelling the attendance of witnesses in proceedings before the commission. The commission may adopt such rules of procedure as shall be in accordance with justice and equity and may make such examination in person and through agents or employees as may be deemed advisable.

ARTICLE XIII.

In all cases where special agreements between the High Contracting Parties hereto are referred to in the foregoing articles, such agreements are understood and intended to include not only direct agreements between the High Contracting Parties, but also any mutual arrangement between the United States and the Dominion of Canada expressed by concurrent or reciprocal legislation on the part of Congress and the Parliament of the Dominion.

ARTICLE XIV.

The present treaty shall be ratified by the President of the United States of America, by and with the advice and consent of the Senate thereof, and by His Britannic Majesty. The ratifications shall be exchanged at Washington as soon as possible and the treaty shall take effect on the date of the exchange of its ratifications. It shall remain in force for five years, dating from the day of exchange of ratifications, and thereafter until terminated by twelve months' written notice given by either High Contracting Party to the other.

In faith whereof the respective plenipotentiaries have signed this treaty in duplicate and have hereunto affixed their seals.

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Done at Washington the eleventh day of January, in the year of our Lord nineteen hundred and nine.

(Signed) ELIHU ROOT. [SEAL.]
(Signed) JAMES BRYCE. [SEAL.]

And whereas the Senate of the United States by their resolution of March third, nineteen hundred and nine (two-thirds of the Senators present concurring therein), did advise and consent to the ratification of the said treaty with the following understanding, to wit:

Resolved further (as a part of this ratification), That the United States approves this treaty with the understanding that nothing in this treaty shall be construed as affecting or changing any existing territorial or riparian rights in the water, or rights of the owners of lands under water, on either side of the international boundary at the rapids of the Saint Marys River at Sault Sainte Marie, in the use of the waters flowing over such lands, subject to the requirements of navigation in boundary waters, and of navigation canals, and without prejudice to the existing right of the United States and Canada, each to use the waters of the Saint Marys River within its own territory; and further, that nothing in this treaty shall be construed to interfere with the drainage of wet, swamp, and overflowed lands into streams flowing into boundary waters, and that this interpretation will be mentioned in the ratification of this treaty as conveying the true meaning of the treaty, and will, in effect, form part of the treaty.

And whereas the said understanding has been accepted by the Government of Great Britain, and the ratifications of the two Governments of the said treaty were exchanged in the city of Washington on the fifth day of May, one thousand nine hundred and ten;

Now, therefore, be it known that I, William Howard Taft, President of the United States of America, have caused the said treaty and the said understanding, as forming a part thereof, to be made public, to the end that the same and every article and clause thereof may be observed and fulfilled with good faith by the United States and the citizens thereof.

In testimony whereof I have hereunto set my hand and caused the seal of the United States to be affixed.

Done at the city of Washington this thirteenth day of May, in the year of our Lord nineteen hundred and ten, and of the independence of the United States of America the one hundred and thirty-fourth.

[SEAL.]

WM. H. TAFT.

By the President:

P. C. KNOX,

Secretary of State.

PROTOCOL OF EXCHANGE.

On proceeding to the exchange of the ratifications of the treaty signed at Washington on January eleventh, nineteen hundred and nine, between the United States and Great Britain, relating to boundary waters and questions arising along the boundary between the United States and the Dominion of Canada, the undersigned plenipotentiaries, duly authorized thereto by their respective Governments, hereby declare that nothing in this treaty shall be construed as affecting, or changing, any existing territorial or riparian rights in the water, or rights of the owners of lands under water, on either side of the international boundary at the rapids of the Saint Marys River at Sault Sainte Marie, in the use of the waters flowing over such lands, subject to the requirements of navigation in boundary waters and of navigation canals, and without prejudice to the existing right of the United States and Canada, each to use the waters of the Saint Marys River, within its own territory; and further, that nothing in this treaty shall be construed to interfere with the drainage of wet, swamp, and overflowed lands into streams flowing into boundary waters, and also that this declaration shall be deemed to have equal force and effect as the treaty itself and to form an integral part thereto.

The exchange of ratifications then took place in the usual form.

In witness whereof they have signed the present protocol of exchange and have affixed their seals thereto.

Done at Washington this fifth day of May, nineteen hundred and ten.

PHILANDER C. KNOX. [SEAL.]
JAMES BRYCE. [SEAL.]

Desirable alterations.—Although the operation of the treaty has been successful and satisfactory to date, and no difficulty has arisen because of the distinction between diversions from boundary waters and diversions from waters tributary to boundary waters, it is deemed advisable in the interest of clearness and to avoid possible future complications, to modify Articles II and III of the treaty so as to extend the jurisdiction of the International Joint Commission to such tributary waters.

Article V of the treaty deals with the matter of the diversion of the waters of Niagara River for power production. When the article was agreed upon it covered the existing situation. Now, however, it is felt to be outgrown. Power installations now under construction will give sufficient capacity to divert water in excess of the limits defined in this article on both sides of the river. There is a steadily increasing demand for power, and whatever diversions may be allowed in the future, it is certain that a market will soon be found for all the power that can be developed. Under the plans outlined in Appendices C and D of this report a greater diversion than that authorized in Article V can safely be allowed, while at the same time the scenic preservation is cared for in what is believed to be the best possible manner.

The amount of water that can be diverted from the Niagara River without serious damage to the scenic beauty of the Falls and rapids has been fully discussed in Appendix C of this report. It was there stated that a total diversion of 80,000 cubic feet per second might safely be allowed if half of it were returned to the Maid-of-the-Mist Pool and if suitable remedial works were constructed. This figure was considered to be a minimum. It is quite possible that when this amount has been diverted, observation will show that a further diversion is allowable.

The reasons for the unequal division of diversions from the upper Niagara River stipulated in the treaty have been given in Section I-1, and it has there been explained that these reasons no longer hold. However correct and just these provisions of diversion limits in Article V may have been in 1910, it appears evident that they are not now satisfactory or just, and that the increases granted should be so apportioned as to make the total diversions from Niagara River for power development equal on both sides of the boundary.

In section F of this report the methods of utilizing the diversion to the best advantage have been considered at some length. The projects in which water is diverted from the Upper River, discharged into the Maid-of-the-Mist Pool and then drawn again from that pool for utilization at a lower stage, were not thought to be desirable. In the case of the two-stage propositions described in Section F it may at times be advisable to draw a certain amount of water from the Maid-of-the-Mist Pool. For this reason it is thought that the treaty should permit the use of water in this manner. Under the present treaty the diversion of water from the Maid-of-the-Mist Pool and around the Whirlpool and Lower Rapids is left under the jurisdiction of the International Joint Commission without any specific limitation. The use of such diversion is so intimately allied with the use of diversions from the Upper River that it seems advisable to include it in Article V.

The introductory sentence of Article V states that "it is expedient to limit the diversion of waters from the Niagara River so that the level of Lake Erie and the flow of the streams shall not be appreciably affected." Diversions from the Maid-of-the-Mist Pool do not affect the level of Lake Erie, but they do affect the "flow of the stream." They also affect the scenic beauty of the Lower Rapids. That the preservation of the scenic beauty of the Falls and rapids was one of the underlying motives which led to the adoption of the treaty is a well-known historical fact which is amply confirmed by the language of the Burton Act, section 4 of which reads as follows:

SEC. 4. That the President of the United States is respectfully requested to open negotiations with the Government of Great Britain for the purpose of effectually providing by suitable treaty with said Government for such regulation and control of the waters of Niagara River and its tributaries as will preserve the scenic grandeur of Niagara Falls and of the rapids in said river.

For these reasons it would be well if this motive were added in the introduction to Article V of the treaty.

In the operation of large hydroelectric plants the amount of water used is not completely under the control of the operators. The action of some consumer, possibly miles away, may throw an increased load upon the generators. The governors will at once open the gates of the turbines, and more water will be passed through them. It thus happens that a company trying to obtain the full benefit of the diversion allotted it will, from time to time, violate the provisions of its permit through no fault of its own. If the limitations of the permit are rigidly enforced, this condition compels the company to leave a constant margin of safety, and habitually develop less power than it is lawfully entitled to, thus sustaining a financial loss which ultimately falls on the community.

These accidental peak loads occur so seldom and are of such brief duration that it is to the advantage of all concerned that the companies should not be penalized because of them. It is desirable, therefore, that all permits should be so worded that such accidental temporary peaks will not be deemed a violation of the permit. The treaty also should preferably be so framed as to allow small accidental diversion in excess of its limitations.

There is a question as to the advisability of altering the treaty so as to deal more in detail with those matters concerning the construction of compensating works other than the "remedial works" at the Horseshoe Falls. It is believed that the treaty is satisfactory now in this respect. Such works are essential, but there has been no difficulty in providing them at Sault Ste. Marie under the present treaty, and there appears no reason why equal satisfaction might not be experienced elsewhere. Joint legislative action of the United States and Canada is necessary, and approval of the projects by the International Joint Commission. Suggestion is made of the advisability of establishing in this connection a permanent commission of advisory engineers, well informed on matters pertaining to the hydraulics of the Great Lakes.

3. INTERESTS OF VARIOUS STATES.

The States of Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, and New York, and the Canadian Provinces of

Ontario and Quebec abut upon the waters of the Great Lakes and the St. Lawrence River, and are affected by diversions of these waters. The character of these effects have been discussed in Section G. The State of Missouri, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana are situated on the Mississippi River below the point where the diversion of the Chicago Drainage Canal is received, and have at least a theoretical interest in that diversion. These 14 States and 2 Provinces have a total population of about 61,000,000, containing 53 per cent of the population of the continental United States and 63 per cent of the population of the Dominion of Canada.

The State of Missouri has claimed a vital interest in the Chicago diversion on the ground that it causes a dangerous pollution of the Mississippi River from which St. Louis and other cities of that State draw their water supply. When they brought suit to restrain the Sanitary District from creating this diversion they were unable to prove that any such pollution occurred, and the Supreme Court dismissed the case without prejudice. It is not impossible that in the future the discovery of further evidence may lead to the reopening of the case. A more detailed account of this case is presented in Section B.

The other States on the Mississippi have but a very small interest in this diversion. It increases the river flow by about 8,800 cubic feet per second and increases the volume and height of floods. As the flood flow amounts to from 500,000 to 2,000,000 cubic feet per second, the increase due to the addition of the Chicago diversion must be inappreciable. At extreme low water the navigation of the Mississippi suffers from insufficient draft. On the 25-mile stretch, between the mouth of the Illinois River and the mouth of the Missouri, extreme low-water flows as small as 25,000 cubic feet per second have been reported. Under such conditions the addition of the Chicago diversion would be a real assistance to navigation. It is estimated that the diversion actually increases the low-water depths by about four-tenths of a foot. The actual assistance to navigation is very small, as the volume of navigation is not great, and the assistance is only needed during a very few weeks of low water in each year. At other times the available depths are ample. Farther down the river, and especially below Cairo, the increase in low-water depths is much less than four-tenths of a foot.

The State of Minnesota is affected by the diversions at the Soo. As the effect of these has been, or soon will be, completely compensated, this State is not directly interested in the question of diversion as far as water levels in its harbors, rivers, and canals are concerned. It has, however, a vital interest in the lowering of the other lakes as its ports handle a very large part of the total lake commerce in ore, coal, and grain.

The other seven States which abut upon the Great Lakes all have their problems of harbors and canals, which are directly affected by the diversions at Chicago, Niagara Falls, and other places. The benefit of these diversions is chiefly confined to Illinois and to New York, and each of these two States suffers somewhat from the diversions of the other.

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